

Multidimensional Risk Communication: Public Discourse on Risks during an Emerging Epidemic

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ABSTRACT

Crisis informatics has examined how institutions and individuals seek, communicate, and curate information in response to crises. The public's communication and perception of risks on social media remain understudied. In this study, we report a qualitative analysis of public perceptions of risks and risk management measures on Reddit during the Zika crisis, an emerging epidemic associated with high uncertainty regarding pathology, epidemiology, and broad consequences. We found two types of perceived risks: ones directly caused by the Zika virus, and ones potentially introduced by authorities' risk management measures. Risk perceptions unfolded along multiple dimensions beyond the imminent and personal level. Reddit users discussed in a speculative way to foresee various risks in the long run or at larger geographical scales. We discuss the multidimensionality and speculative nature of risk perception on social media, and derive implications for crisis informatics research and public health research and practice.

Author Keywords

Crisis informatics; public health crisis; Zika virus; biological crisis; public participation; social media; emerging epidemic; risk perception; risk communication.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g. HCI): Miscellaneous; J.3 Life and Medical Sciences, Health, Medical Information Systems.

INTRODUCTION

Dealing with crises is one of the most important and complex tasks facing contemporary societies. Crises often pose high risks to individuals, institutions, and society, including deaths, injuries, economic losses, disruption, and chaos. "Risk" refers to the possibility that an undesirable

state of reality (adverse effects) may occur as a result of events or activities [60]. Crises bring both known and unknown risks. Much of the difficulty in dealing with risks involves ascertaining potential risks and the severity of potential consequences [60]; "The essence of risk is not that it is happening, but that it *might be* happening" (p.2) [1].

Crisis informatics research has focused on informational practices where the general public use information and communication technologies (ICTs) to seek, communicate, and curate useful information in response to crises (e.g., [32,33,40,47,58,68,75,79]). Informational practices could help prevent immediate risks from happening via propagating crisis-related information (e.g., warnings about immediate risks that call for quick actions) [75]. Informational practices could facilitate disaster response by enhancing situational awareness and enabling digital volunteering when negative consequences already take place or are happening [35,74,79].

However, the public's risk perception remains underexplored. Risk perception refers to people's interpretations, opinions, and judgments regarding risks [71]. Individuals typically make decisions based on their perceptions of risk [25]; and their individual decisions may not only impact themselves but also add up to larger impact. Further, analysis of risk perception can reveal "what constitutes dangers, threats and hazards and for whom" [1]. Understanding the public's risk perception can help identify the information critical to them, as well as aid researchers and officials to understand and anticipate public response to risks, thus improving communication between laypeople, technical experts, and policymakers [23,72].

In this paper, we address this gap by investigating the public's risk perception on social media in an emerging epidemic, the Zika virus crisis [59]. Emerging epidemic diseases— infectious diseases that have newly appeared or that have been known for some time but are rapidly increasing in incidence or geographic range [50] — are a type of crisis that can cause severe impacts (e.g., morbidity, mortality, and disability) on large populations. Risks associated with emerging epidemic crises are often unfamiliar, exotic, and rarely readily discernible to the general public, because such diseases involve "organisms that cannot be seen and diseases and symptoms that have not been evident in the general population" (p.44) [3].

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Emerging epidemic crises require public health professionals to conduct complex epidemiological and experimental studies to understand the disease and its likely spread and effects in populations. When critical knowledge is missing, or is yet to be disseminated to the public [27], high scientific uncertainty is at play, which results in the situation that ordinary citizens utilize accessible information which may not be directly relevant to interpret crisis situations and figure out potential risks [24,73]. Specifically, we examine the public's risk perception of the Zika virus crisis, including the perceived risks and perceived risk management measures. We conducted a qualitative content analysis of Zika-related risk communication on Reddit, one of the largest social news sites in the world. Our working definition of risk communication is “any public or private communication that inform individuals about the existence, nature, form, severity, or acceptability of risks”, which can be “from any source to any recipient through any channel” (p.6) [57].

Our study makes four main contributions to crisis informatics, and public health research and practice: First, we present a detailed analysis of risk communication on Reddit during an emerging epidemic crisis, a type of crisis that remains understudied in crisis informatics. Second, we uncover specific types of risks that the public perceived and multiple dimensions of these risk perceptions (time horizon from imminent to long-term and scope from personal to planetary). Third, we describe the practices that Redditors used to speculate about risks and propose risk management measures when facing high scientific uncertainty, which has important value for crisis informatics research and public health agencies. Lastly, we contribute to public health research by documenting the utilization of social media in bottom-up efforts to articulate risks and risk management measures.

BACKGROUND

Zika virus was first discovered in Uganda in 1947 in monkeys, and later identified in humans in 1952 in Uganda and the United Republic of Tanzania [78]. Zika did not become a global concern until in October 2015 when Brazil reported an increase in the number of newborns with microcephaly—a medical condition in which newborn babies are born with underdeveloped brains—and an association between Zika virus infection and microcephaly. By the end of 2015, the Brazilian Ministry of Health estimated that the cumulative number of infections in Brazil ranged from 440,000 to 1,300,000 [31]. By January 20, 2016, locally-transmitted cases had been reported to the Pan American Health Organization from Puerto Rico and 19 other countries or territories in the Americas [31]. Suspecting the causal link between Zika and microcephaly, the World Health Organization declared a public health emergency of international concern on February 1, 2016 [85]. By November 18, 2016, WHO reported that there was now sufficient evidence that Zika virus infection was the cause, and ended the declaration of it as an emergency [86].

However, it does not mean that the Zika virus is no longer a public health crisis. On the contrary, WHO described the consequences of Zika virus infection as “a highly significant long-term problem” that requires a “robust longer-term response mechanism,” and stated that WHO was shifting focus and resources accordingly [86]. WHO has claimed that WHO's experience over 2016 “has shown that Zika virus and the associated neurological complications represent a long-term public health challenge” [81]. Zika virus outbreak is perceived to be an especially egregious public health crisis because of the risk it poses to newborns [80]. While Zika virus infection seems to be a mild disease in the general population, as it mainly impacts women of child bearing age and their partners, and it only leads to mild or even no symptoms, its potential consequences to the fetus and newborn are profound [15].

Scientists have identified several transmission pathways for Zika, including through mosquito bite, from mother to child, sexual behavior, blood transfusion, and laboratory and healthcare setting exposure [10]. Many infected people are asymptomatic and might do not know they were infected [11]. The symptoms can be mild or resemble the Dengue fever [87]. Much about Zika virus remains unknown. At the time of writing this paper, the U.S. Centers for Disease Control and Prevention (CDC) claims that “there is no vaccine or medicine for Zika” [9]. WHO also emphasizes that there are still “significant knowledge gaps around Zika virus and a lack of historical data on its vectors, transmission dynamics, and geographical distribution” [82]. To make the situation even more complicated and more politicized, Zika's linkage to microcephaly touches on the issue of abortion and birth control that is highly sensitive due to its entanglement with human rights, religious beliefs, and politics. Extreme scientific uncertainty and sensitivity characterize this epidemic crisis, which may impact how the public perceive its risks.

While Zika is the focus of the present paper, it is important to note that a number of persistent factors may be creating a breeding ground for epidemics around the world [84]. These include high population density, migration, poverty, conflict, climate change, and international travel [84]. The incidence and impact of crises like Zika, SARS, and H1N1 to name but a few is likely to pose ongoing crises and perhaps crises of increasing severity, making epidemic diseases a crucial area of research for crisis research.

RELATED WORK

Risk Communication and Risk Perception

Risk communication has attracted enormous scholarly attention [4,53,66]. Risk communication has different definitions, broad or narrow, depending on the intentionality, content, audience directed, source of information, and flow of message [57]. Broadly, it can refer to “any public or private communication that inform individuals about the existence, nature, form, severity, or

acceptability of risks,” which can be “from any source to any recipient through any channel [57]”. Narrowly, it only refers to how scientists and technical experts intentionally transfer risk information “designed to respond to public concerns or public needs related to real or perceived hazards,” which is “from experts to nonexperts through designated channels” [57]. In public health, researchers and practitioners usually use the narrow definition of risk communication which emphasizes the process of informing and educating the public about risks by scientists, public health officials, and other kinds of experts to persuade the public to adopt more healthy and less risky behaviors [3,57]. In this paper, we adopt the broad definition to highlight the importance of ordinary citizens as risk communicators [57].

Risk perception describes people’s interpretations, opinions, and judgments regarding risks [71]. Individuals and social groups usually develop risk perceptions with a dearth of information about risks [38]. Much research on risk perception has focused on psychological aspects of risk perception using psychometric methods. Such studies focus on producing quantitative representations of people’s risk perceptions and ratings of perceived risks [71]. In this research, lay people’s risk perceptions are typically portrayed as *ill-informed* or *biased* while experts’ risk perceptions are considered *accurate* and *scientific* [46]. Such psychometric approaches may fail to capture the influence of the sociocultural context on risk perception [46]. Sociological and anthropological studies of risk perception focus on the social and cultural factors surrounding and shaping perception and acceptance of risks [46]. Some scholars consider risk perception of experts as much as lay people as inevitably the outcome of sociocultural processes [46] and risk as a sociocultural construct [1,7,77], which calls for more attention into the sociocultural processes through which risk-related phenomena is defined [77]. Our study utilizes a social constructivist approach to analyze risk perception and communication on Reddit, seeing risk perception as something that is created and re-created through social processes and within specific sociocultural contexts.

Risk in Crisis Informatics Research

Crisis informatics research has focused primarily upon how community members and the general public used information and communication technologies (ICTs) (e.g., blogs and social media) to seek, communicate, and curate locally useful information in response to natural and manmade crises (e.g., wildfires, hurricanes, floods, earthquakes, and violent crises). Such informational practices could help nearby residents make informed decisions and the general public stay informed how events are unfolding at ground zero of a crisis [32,33,40,47,58,68,75,79]. The communicated and curated information included information about what had occurred or were happening and also immediate risks (e.g.,

information on official “watches” and “warnings” issued during natural disasters).

Another strand of crisis informatics research focuses on how emergency response professionals use ICTs and how social media can serve the needs of professional emergency responders. Emergency response professionals shared information and coordinated on social media [26,67]. Emergency response organizations also used online media to communicate with the public about the crises [34]. Social media can also potentially provide crisis-reporting data to emergency response professionals [76].

While previous crisis informatics research has focused on how the public and authorities use ICTs in information work to respond to disasters, little attention has been paid to the public’s risk perception related to crises and the role that social media plays in risk perception processes. One possible explanation is that previous research has focused on manmade and natural disasters such as bombings, floods, and hurricanes, where the risks are relatively immediate and straightforward for the public, thus more easily recognized and understood by members of the public. The research of Gui et al. [28] is an exception, which investigated how people used social media to assess risks associated with their personal travel plan.

Our study specifically focuses on the public’s risk perception in an emerging epidemic crisis. Different from Gui et al. [28] which uncovers the personal, individual level travel risks perceived by the ordinary citizens, our study investigates citizens’ perceived multi-dimensional risks and risk management measures.

Social Media in Emerging Epidemic

Existing public health research has dominantly concerned the instrumental value of social media to public health authorities including government agencies and researchers. Existing research shows that public health practitioners and researchers can mine social media data for actionable surveillance on disease activities which can inform outbreak management (e.g., [6,13,18,52,69]). Some public health agencies have formally adopted social media data for surveillance and outbreak management. For instance, the New York City Department of Health and Mental Hygiene used social media monitoring to inform the responses to Ebola and Legionnaires’ disease outbreaks [30].

Public health research has emphasized social media’s important role in supporting public health agencies to disseminate disease outbreak-related information [14,49]. Public health agencies have also used social media for risk communication. For example, during the H1N1 Influenza epidemic, governmental institutions such as CDC and the United States Department of Health & Human Services (HHS) disseminated information to the general public through social media and other websites [20].

However, challenges exist as to how social media can support the communication between the public and public

health agencies. Public health agencies might employ social media strategies that do not match and fail to attract average social media users' interest [29]. When left in the dark with high uncertainty, average citizens rely on their own to develop plausible explanations about the public health crisis situation [41].

Existing research has mostly adopted a top-down approach when framing the role of social media in the communication between the public and public health authorities. More recent studies have begun to identify the limitations of this approach. Our work aims to identify the role that the public can play in risk communication, and to derive implications for public health practices.

METHODS:

Reddit is our study site of risk communication related to the Zika virus crisis. Reddit ranked the 4th most visited website in the United States and 15th in the world by the time of writing this paper [2]. Reddit allows users to aggregate information and report news in various ways, ranging from redirecting the audience to external news sites to actively curating content from local sources [43]. A thread has two forms: links or text post. Users can comment on a thread. Analyzing the public's communication on Reddit can allow us to study how the general public discussed about the crisis. We utilized a grounded theory research design [17] with the primary data collection and analysis being qualitative content analysis [42].

Data Collection

In January 2017, about a year after the initial outbreak of Zika virus in January 2016, we used the search functions provided by Reddit to look for Zika-related user discussions. The keyword we used was “Zika,” because our literature review and understanding of the public health domain indicate that “Zika” unambiguously refers to the virus and has no alternative names. In contrast, people might use “swaine flu” or “H1N1” to refer to the same influenza. The search function returned both subreddits (i.e., “community message boards curated around a particular topic” [43]) whose names contained “Zika” and threads whose titles contained “Zika.” The threads came from hundreds of subreddits. We located five subreddits (/r/Zika_virus, /r/Zika_English, /r/zika_sp, /r/Zika_pt, and /r/Zika_fr) that directly addressed Zika-related topics. However, all these subreddits were largely inactive, judged by the number of subscribers and the number of comments per thread. To the opposite, we found Zika attracted heated discussions across multiple general news discussion subreddits, such as ‘/r/politics,’ ‘/r/worldnews,’ and ‘/r/news.’ For example, a Zika-related thread from ‘/r/politics’ had 2718 comments. Another from ‘/r/worldnews’ attracted 2593 comments. Considering that Reddit users could easily move across multiple subreddits and that the top-commented threads belonged to subreddits that were popular with more than 10 million subscribers, we deemed that, for studying the public's risk communication, it was suitable to investigate

all the subreddits that paid attention to Zika as a whole, instead of focusing on any individual subreddit.

On January 30, 2017, we used TACIT [19], an open-source data crawling and analysis tool to collect Zika-related threaded conversations from Reddit. We only used Zika as the search keyword. The Reddit API provided five filter criteria (top, new, comments, relevance, and hot). Post score is viewed as a form of social reputation on Reddit. We used each of the five criteria to retrieve 1000 Zika-related threads, and combined them into 1486 unique posts and 74,087 associated comments. We used MySQL to store all the posts and comments, as well as their metadata including time of creation, author name, subreddit name, score, number of upvotes, and number of comments (for posts only). The threads spanned over 346 subreddits following a long-tailed distribution, with 44% threads in the top 10 subreddits. We found seven languages across the 1486 posts, including 1439 English posts (96.84%), 31 Portuguese posts (2.09%), nine Spanish posts (0.61%), two German posts (0.13%), two French posts (0.13%), two Japanese posts (0.13%), and one Croatian post (0.07%). While English was the dominant language used across the subreddits in our dataset, posts in other non-English languages appeared primarily in subreddits dedicated to countries, regions, or entities that used these languages. For example, the 31 Portuguese posts came from either /r/brasil or /r/portugal, the nine Spanish posts belonged to /r/mexico, /r/pedemos, /r/argentina, and /r/puertorico, the two French ones were from /r/france and /r/quebec, the two German ones were in /r/de, and the one Croatian post came from /r/Serbia. The two Japanese posts were irrelevant to Zika virus, because they were discussing a Japanese cartoonist whose name is Zika, and came from the /r/dbz subreddit that focused on the Japanese anime “Dragon Ball.” We removed non-English posts because no author spoke the other six languages. We also removed posts from /r/dbz where Zika referred to a cartoonist. After this screening process, 1417 posts remained in our final dataset.

Our dataset from Reddit API did not contain biographic attributes that can characterize the population studied in this paper. To our best knowledge, Reddit does not collect such information from its users. Therefore, we do not claim that our findings about patterns of risk perception and communication can be generalized to a larger population outside the Reddit platform. However, considering the important role of social media in supporting today's public discussions among large numbers of people, it is reasonable to state that our study of a social media site still holds theoretical implications for understanding patterns about the general population.

Data Analysis

As is characteristic of interpretive research, our research question evolved through the analysis process. We began with a very general question, namely, what topics engage the public? But we quickly found that most Reddit

discussion of Zika during the emerging epidemic crisis was related to Zika risks. We decided to re-focus our research question around how people used social media to discuss risks posed by the Zika virus crisis. We used a grounded-theory approach [17] to answer this research question.

Two researchers first randomly selected 20 posts across seven different subreddits as well as their associated 839 comments. Each first read through all the discussions to determine major themes that these discussions concerned about in terms of risks. Two researchers then met again to discuss their findings to determine that risk-related communication was focused upon two integrative components: 1) how Reddit users perceived risks, and 2) what management strategies Reddit users brainstormed to manage these risks. Under the first main theme, we further identified subthemes including the types of risks that people discussed, as well as the dimensions of risks that people discussed. Under the second main theme, we found that people also discussed coping strategies that were related to the multidimensionality of perceived risks. We realized that multidimensionality of perceived risks was a distinct feature within this dataset of public discourses.

Two researchers further randomly selected 50 posts and their associated 3295 comments. We then used the codebook generated during the first phase to examine this new dataset, with sensitivity to emerging themes. During this phase, we found that the two major themes remained, while subthemes under each of the major themes were expanded. As we coded through all the posts and comments, we determined that we have reached theoretical saturation [17,65], meaning that no new themes emerged. We further randomly sampled 150 posts with their associated 4871 comments to test our generated codebook. In total, we coded 200 randomized posts and their associated 7196 comments. Within these 200 posts, we identified 73.5% posts ($n=147$) containing comments concerning risks.

FINDINGS

We found two types of perceived risks related to the emerging Zika epidemic: 1) **Risks directly caused by the Zika virus**, including risks on or caused by getting infected, infected babies, and affected population in general. 2) **Risks that might be introduced by risk management measures** including official policies and actions to combat Zika.

The first major type of perceived risk directly related to Zika that was most often and most intensively discussed on Reddit was the risks that Zika virus infection posed to pregnancy, and having a fetus or baby with microcephaly. Microcephaly and unknown effects on affected people caused by Zika were perceived as major risks that individuals could not fully understand but had to manage through actively preventing either be infected by Zika or pregnancy.

The second major type of perceived risks about the emerging Zika epidemic discussed on Reddit was focused

on the risks posed by Zika mitigation measures. Posters generally expected mitigation measures to be taken to address Zika, but there were wide range of speculations about what these measures might be and what risks they might pose. The two topics that tended to dominate conversation about risks of Zika mitigation measures were *risks of mosquito control measures and public funding of Zika mitigation*. Posters on Reddit actively discussed potential risks of public health measures to control mosquitoes such as spraying insecticide and releasing genetically modified mosquitoes to fight Zika virus. People also discussed the risks of delaying Zika mitigation measures centered on perceived challenges to securing government funding for intervention. For example, many people expressed concerns regarding the delay of passing a Zika virus prevention and research spending bill in U.S. congress. A researcher from a public health laboratory shared their experience from directly investigating Zika, and claimed that the delay had risks: *“This is playing with people's lives. I work in virology at a PHL[Public Health Laboratory], we can't buy the necessary supplies to even ramp up for Zika... PHLs are dealing with this right now as the fiscal year has just changed...state budgets are not being passed because the states are waiting for this federal funding bill to pass.”* This user confirmed that state-level public health laboratories were hindered by lack of federal funds, endangering public health.

Next, we first unpack the multiple dimensions of Redditor's perceived risks in detail. Then we report their proposed multi-dimensional risk management measures.

Anticipating Multidimensional Risks

A hallmark of emerging epidemics such as Zika virus is that much remains unknown about the crisis, so people form risk perceptions about both known and unknown risks. Our analysis of risk perceptions about Zika as it emerged revealed that Redditors discussed risks along two dimensions—time and scope. The **temporal horizon** for potential risks ranges from imminent (very near term) to long-term and the **scope** of potential Zika risks ranges from the personal to the global.

Temporal dimension of risk perception: from Imminent to long-term

The public perceived **imminent risks** associated with both Zika virus and Zika virus mitigation measures. Perceptions of imminent risks largely centered around personal risks of getting infected. For instance, similar to Gui et al. [28]'s findings, many people discussed the imminent risks of getting infected associated with living or planning to travel to a particular area. The following data exemplifies Redditors' concerns regarding imminent risk of get infected:

My wife and I are going to Cabo San Lucas in January. We want to try to get pregnant but are aware of the Zika virus' presence in Mexico... Some of that information, however, is 6+ months old so new reliable literature is hard to come by. Can anyone tell me if Cabo San Lucas is a safe enough

place to try or should we reconsider attempting to conceive there?...We want to try while we're there but want to be cautious just in case.

The Redditor submitted the post in late December 2016, trying to figure out the imminent risks posed by traveling to a specific locale.

Some discussion about perceptions of imminent risks also centered on risks of Zika mitigation actions, although these risks were discussed to a lesser degree than the risks of Zika infection. This took the form of Redditors discussing the imminent risks of known plans to spray for mosquitoes in specific locations. One common imminent risk described was that the insecticide that might be sprayed by official agencies to kill mosquitos would kill other species immediately and collaterally. For instance, one Redditor justified their perception of the risk to bees by citing media reports that a county in South Carolina killed millions of bees when spraying to eradicate mosquitoes: *"Hopefully they don't kill all the bees like they did in that county in South Carolina."* The following snippet is from an exchange between posters discussing risks of a specific plan to spray for Aedes mosquitoes in User 1's community.

User 1: I live in the spray area and breed shrimp in my house. I guess I should cover the tank? Safe for pets my ass.

User 2: They're only supposed to spray standing bodies of water, but yeah I wouldn't risk it.

User 1 does not believe the official explanation that insecticide is "safe for pets" and articulates a possible imminent risk that the insecticide may hurt the shrimp in their house. User 2 states their understanding of the official policy, but urges caution.

Redditors also discussed a variety of **long-term risks**, such as the long-term risks the Zika virus might pose for infected babies and their families and the long-term risks which might introduced by the official Zika mitigation measures. Long-term risk perceptions often took on a more speculative tone. Because Zika was still an emerging crisis, there was much scientific uncertainty about the pathology and epidemiology of Zika thus developing risk perceptions about Zika was more difficult. Many Redditors speculated that Zika virus may pose unknown health effects long after initial infection that would be unknown for years. For example, under a post which shared the news that 1 in 4 people in Puerto Rico would have Zika by the end of 2016, a commenter expressed the following:

What's more worrying to me is the lack of data about long term sequelae. We keep finding out that some cancers and diseases are result of past viral infection. You might have had Zika when you were a kid... You got over it. 15 to 25 years later, you develop a novel cancer...

This post exemplifies many such comments that express deep uncertainty about how Zika acts in the body and the

long-term effects of the virus. Because of the scientific uncertainty regarding the Zika virus, the commenter did not have a full grasp of many aspects of Zika. Such comments sought information both about what was currently known about concrete health risks (short and long term) associated with Zika. Another function of this speculative conversation was to try to grasp the parameters of the space of uncertainty. This user was wondering how bad Zika could be, attempting to speculate about potential worst-case scenarios in the face of a large gap between what was known and what remained to be discovered.

One important aspect of risk perception conversation about long-term risks posed Zika as it was emerging had to do with linking the risks of Zika virus to other life experiences and/or other similar experiences of infectious disease. For instance, a user posted, *"We don't know the future of these children, and working with critically ill kiddos every day has made me wary of any added risks. Even without microcephaly, there may be long term effects."* This poster is drawing on lived experience with severely impaired children to create a more fully formed picture of the risks posed by Zika. Because of the scientific uncertainty about the effects of the virus that existed during this emerging crisis, the poster speculates broadly, pointing out that Zika virus in pregnancy may cause long-term impairments to exposed fetuses even if microcephaly is not present.

Some users compared the Zika virus with other epidemic crises, and used their knowledge of the effects of these other crises to form perceptions about the long-term risks of Zika virus. For example: *"This is worse than the spread of diseases like dengue or yellow fever, because the social cost of caring for citizens with microcephaly is life-long (even if their life expectancy may be somewhat reduced)."* This poster is comparing known effects of Zika with the known effects of other infectious diseases to develop a perception that Zika is more serious because of the potential to cause birth defects with long-term costs for individuals and societies. Such contextualization of Zika risk perception added depth and texture to posters perceptions about the long-term risks posed by Zika directly.

Some people also speculated that in the long-term, there would be mutants of Zika virus. For instance, one user commented, *"I think a very important problem we need to consider, and always keep considering is that, vaccines are a temporary fix. Viruses will evolve around these vaccines, becoming more and more dangerous, how do we stop that? How do we deal with that?"*

Commenters also discussed possible long-term risks related to the Zika mitigation measures against Zika. For example, under the post mentioning that officials of a county would spray insecticide to kill mosquitos in a local community, a Redditor commented:

So we have to flood our communities with poison in the hopes that a few less children will be born with defects? I'm

not a pathologist, a doctor, or health professional, but if something is toxic enough to wipe out mosquitoes and bees immediately, might have health consequences for many more people in the future. The chemical to be used is Pyrenone 25-5, ...This is directly from the product description on environmental hazards:(citing the description) ...I understand that the levels are low enough to not be deadly to humans, but still: From a Santa-Clara study on spraying due to fears about the west Nile virus (a proposal that included using the SAME spray) This scorched earth policy is only making life more difficult for us in the long run.

The user cited multiple sources, including the description of the insecticide and an open letter written by physicians and scientists, to engage in informed speculation about the long-term risks associated with insecticide that the county planned to spray.

The Scope of perceived risks: From the Personal to the Global

Many posters discussed the perceived risks of Zika related to themselves and their immediate families and the specific ways in which they managed these risks. Such discussion often focused on possible risks related to traveling and pregnancy, which has been discussed in previous work [28] and the above section.

Posters also discussed various risks in different scopes beyond the personal, including risks at the neighborhood, city, region, national, and international level. For example, a user commented under the poster which shared a news regarding Zika cases in India, *“In poorer neighbourhoods though, pregnant women being especially affected is a possibility....”* This user was attending to the geopolitics of epidemic crises, noting that areas with fewer resources faced increased risk from the Zika crisis.

Discussion of Zika risks was often shaped around specific geographic locations, whether they be cities or regions (e.g. “São Paulo” and “Florida”). Some Reddit posters discussed risk at the national level. For example, in the following exchange a Redditor discuss Zika virus risks for Singapore as compared to other affected countries: *“Singapore has far higher population density than Brazil...Therefore, potential outbreaks are more dangerous in Singapore, because we are talking about a very densely populated area of people in which infected mosquito colonies to multiply and spread the disease... Singapore outbreak has started within the last 10 days and the number of confirmed cases is growing quickly...Think about that: Singapore is renowned for being one of the cleanest and most sanitary cities in the world.”* Yet the virus is still spreading rapidly. This person is actively connecting the emerging Zika epidemic to their nation’s population density and describing risk in terms of Singapore’s attributes in relation to the spread of Zika.

Posters also speculated about Zika risks from an international perspective. For instance, one user posted,

“For myself? No. I have no plans of ever being pregnant, and from my understanding it isn't particularly threatening otherwise. From a global standpoint? Very. Women who are in the part of the world affected are already more likely to deal with social and financial inequality. Adding a disabled child to the mix is not going to help anyone, and I couldn't imagine this won't widen income and opportunity gaps. Also, a lot of affected nations have very strict and inflexible laws regarding birth control and abortion. Risking women's lives to sustain unhealthy and sometimes unlikely to survive fetuses is going to become an even bigger reality for a lot of people very soon....”

The Redditor did not perceive any risk related to her personal scope, however, looking at the global scope, the Redditor worried about the global risks on women in general and some effected nations. Further, this Redditor discusses Zika risk from the viewpoint of complex geopolitics, pointing out that women in different countries with different cultural restrictions and reproductive laws will be effected differentially by Zika and vary in the degree to which they are able to carry out future public health advice (strictly preventing pregnancy) to prevent the possible risks of Zika on fetuses.

Perceptions of Multidimensional Risk Management Measures

Because of high scientific uncertainty, Reddit poster’s discussion of risk tended to be speculative in articulating present and future risks at different levels, in contrast to discussion of risks in other types of crises. Risks posed by natural disasters such as a hurricane are large, but they are also more straightforward and tangible thus easier to perceive. The uncertainty inherent in the emerging epidemic made it difficult for Redditors to discuss risk management measures for Zika virus. Still, Redditors actively discussed risk management measures. They commented upon existing measures and brainstormed future preventive measures. Discussion of preventive measures ranged from what preventive measures individual should take to avoid getting affected, to what citizens themselves should do collectively to better cope with the emerging epidemics, to what kinds of emergency response public health agencies and media should provide, to what policies can be made to take care of affected population in the future. These diverse measures, individual and collaborative, emphasized on both imminent and long-term risk preparedness at personal, neighborhood, city, country, and international levels.

To tackle individual level imminent risks of Zika infection, people discussed preventive measures that individuals could take. Some users proposed preventive measures based on knowledge and past experience in handling similar epidemic crises. One user posted, *“What can we do about it? I'd anticipate (hope) the first messaging we'll hear will be around avoiding mosquitos (wear repellent, long sleeves and pants, stay inside at dusk and dawn, rid your yard of*

standing water, etc). Not a virus-expert but I remember the West Nile Virus scare which was handled similarly. This user drew on knowledge of a past disease crisis with the same disease vector, West Nile, to suggest the likely official advice that would soon emerge about how to prevent Zika infection. It is important once again to note how posters drew on multiple sources of information in the process of forming and communicating perceptions of risk.

Another common occurrence on Reddit was users offering advice to people going to travel to risky areas: *"A few things you could do: * Obviously, talk with a healthcare professional before going * Both take measures to avoid contracting it during (wear anti-mosquito product, wear long-sleeves and pants, stay indoor although that last one is a bit much for a trip abroad) * See if there is a test you can take after."* This comment is an example of concrete advice passed between users related to managing Zika risk.

Redditors also discussed collaborative actions they could engage to manage the perceived risks at a broader level. Examples included taking community-level preventive measures as well as reflecting on, monitoring, and advocating for government, media, and public health agencies' emergency response. One common focus of such discussions was on collective actions ordinary citizens could take in their local communities, such as draining standing water and spraying and fogging for mosquitoes. The following post is an example:

I like to think of this in terms of how you can protect yourself, and how we can protect communities...At the community/population health level, mosquito control efforts are key...Aedes aegypti mosquitoes are known to transmit Zika virus. This mosquito likes urban environments and can reproduce in very small pools/puddles of water. Ensuring there is no free standing water around houses (e.g. in gardens, garbage, etc) is key. Sometimes larvicides are used as well if the water cannot be drained. In addition, adult mosquito populations can be controlled with spraying or 'fogging'.

Another user emphasized that everyone could help fight the crisis by raising local communities' awareness and fighting online misinformation: *"...there are very sensible things everyone can do in the face of any public health concern. ... Anything to get the public to wake up. Keeping the local community alert is the first step toward a successful health care response. It is important to bring awareness to the public when the vast majority has no knowledge of how to deal with things a developed country such as ours mostly regard as a distant memory. People posting here and elsewhere are adamantly asserting there are no vectors to transmit any possible epidemic when the opposite is true. There is a lot of misinformation and ignorance to be fought."*

People also pointed to the importance of reflecting on past emergency responses of government, media, and public health agencies, monitoring the ongoing responses, and

advocating for improved response in the future to manage both the imminent and long-term risks at local and societal level. The following exchange demonstrates the viewpoint many Redditors took that there was a keen need for citizens to take an active role in following and monitoring emergency response in their communities and holding these agencies accountable for the side effects (in this case, ecological side effects) of their response.

Post title: *US beekeepers fear for livelihoods as anti-zika toxin kills 2.5m bees*

User 1: *Well, part of the problem is they were stupid about when they sprayed...But, common sense would suggest that bees would be out and about in daylight and mosquitoes would be more likely to be out at night.*

The county officials argue that they gave sufficient notice. They posted a notice on the County page 2 days before spraying and on their Facebook page a day before spraying. They also claim to have called the beekeepers they knew of and had contact info for, which wasn't everyone, apparently.

To me, 2 days advertised on the internet is not sufficient information. There should have been notices mailed out, to everyone in the county -- beekeeper or not -- at least a week in advance. It should have been mentioned on the local news and in the local newspaper...This mass bee death could have been avoided, but, for some reason, there was this big rush to do the spraying without much planning or notice, and then, surprise! it didn't quite work out.

User 2: *Lets be honest here how many people here follow there local town or cities twitter or facebook page. Its not even a good way to reach the average person because very few people even know that there city/town has a page let alone sign up to it.*

These users criticized the emergency response of local agencies that killed millions of bees. They argued that the agencies sprayed at the wrong time when the bees were out while the mosquitoes were inactive. They also pointed out that notifying the public about the upcoming responses via local town or cities' social media pages was not sufficient, which might have implications for the local agencies' future outreach measures.

People also reflected on current emergency responses and discussed the emergency response that public health agencies and media should provide. For instance, under a post which shared the news that there were 36 more confirmed cases in Singapore, users reflected on the media's focus on updating cases:

User 1: *...The media should be focused on galvanizing the whole of Singapore to check for mosquito harbouring sites especially in their own homes wherever they may stay, and not be focused on which region has how many cases - as that may lead some to think "Hey I stay in Jurong, so I'm safe for now".*

User 2: ...I do agree with your point that the different regions and hotspots thing is a little overdone and may lead people to believe that as long as they are not within those areas they are 'safe'.

DISCUSSION

We reported a qualitative analysis of risk communication on Reddit during the Zika crisis, detailing types and dimensions of perceived risks and risk management measures. Next, we will discuss in detail the characteristics (multidimensionality and speculative nature) of risk perception about the Zika crisis as it plays out on social media. We will articulate the practical implications for crisis informatics and public health research and practice.

Multidimensionality and Speculative Nature of Risk Perception

Epidemics are usually extensive in their potential reach, likely impacting a large population and causing long-term effects on people's health. The current top-down model of public health emergency response focuses on persuading citizens to be compliant with emergency measures [3,5,16,45,51,66], and casts ordinary citizens in a receptive role, expecting them to accept and digest information transmitted from the authorities and comply with guidelines [3]. The underlying assumption is that the response to public health emergencies must be disciplined by systematic data and sufficient evidence; that lay citizens' perceptions of risk are usually biased and ill-informed; and that lay citizens need to be informed, educated, and persuaded [25].

When average citizens have little legitimacy and authority (e.g., access to laboratory test, scientific knowledge) in explaining Zika, social media platforms such as Reddit in this study become a hotbed for citizens to develop their perceptions and speculations.

Our findings demonstrate that perceived risks spanned multiple dimensions (see Figure 1). Proposed risk management strategies were similarly multidimensional.

Long term	E.g., long-term risks on infected babies;	E.g., long-term risks on all the affected women and nations around the world
Imminent	E.g., imminent risks on pregnant women and fetuses; immediate risks on local neighborhoods	E.g., imminent risks on national health
	Personal, local	National, international, and global

Figure 1. Dimensions of perceived Zika risks

The multidimensional risk perceptions were produced through Reddit users' engagement in what we called "risk speculation" where they hypothesized, conjectured, guessed, and imagined risk possibilities. Posters also rationalized their speculations using various evidence drawn from a

variety of information sources. The speculative activities of Reddit users are not irrational or baseless. Rather, this speculation process can be seen as a process of citizens drawing upon available information to conduct logical reasoning to generate and articulate the perceptions about uncertain possible futures that may come to pass. The nested discussion structure of Reddit allowed its users to gather and engage with various types of available information to develop risk speculations. The available information included known facts, available authoritative information, and their lived experiences. For example, when the Zika virus crisis just started to emerge, a Reddit user recalled that in the West Nile Virus outbreak which is also mosquito-borne, citizens received instructional messages about how to avoid mosquitoes. The user thus speculated that the messaged guidelines might also work in managing risks of getting infected by Zika virus. During the process of speculation, Reddit served as a transmitter and social amplification station [39], allowing messages about risks to be transmitted, discussed, intensified, and altered.

Multidimensionality was the dominant salient characteristic of risk perceptions about Zika. Risk speculation was a secondary, salient pattern conceptually related to multidimensionality. Multidimensionality was only able to emerge when people engaged in speculation to uncover possible risks beyond the perceptible. Therefore, multidimensionality and speculation are mutually constitutive.

Implications of the Multidimensional Perspective

The multidimensional perspective (Figure 1.) can be a valuable lens for the identification of latent risks that were overshadowed by immediate risks that were sometimes numerous, and the construction of a more thorough set of risks. For example, past emerging epidemic crises such as SARS and Ebola presented uncertain risks that eventually happened extending over a long-term time horizon and across multiple scales [48,54,55]. Manmade and natural disasters are also likely to introduce long-term and large-scale risks, although these risks may not arise directly from the initial crisis and become readily recognizable. For instance, terrorist attacks may introduce long-term risks such as mental health effects or political ramifications [36]. Hurricanes can impose long-term health and economic risks [8], as shown in the Hurricane Katrina in 2005 [12]. Therefore, the perspective can be both prescriptive and generative in crisis informatics research when the focus is on risk and risk management. Retrospective analysis of existing social media data generated during natural or manmade disasters might reveal discussions of a variety of risk types.

The multidimensional perspective can be a valuable asset to existing crisis response mechanisms in multiple ways. First, it can bring in perspectives on long-term risk and management, altering the current equilibrium in which authorities are likely to emphasize short-term effects and

risk resolution. Second, it can enable reflection upon both current and future risk management practices. The local and experiential knowledge revealed on social media can complement the knowledge of professionals and augment professional risk analysis. For example, citizens may possess useful information concerning their own and their community's exposure to risks, as evidenced by the local beekeepers' criticism that agencies sprayed at the wrong time when the bees were out while the mosquitoes were inactive.

The multidimensional perspective also engenders a critique towards the common risk communication practices in the public health domain that often focus on one dimension (the personal scope) of risks [3], and emphasize the top-down mode of dissemination of personal risk-related information to the public to encourage desirable behavior changes to manage the personal health risks [45]. As our study showed, ordinary citizens think beyond the personal scope to articulate and speculate about multidimensional risks and management measures. Thus, it is important for public health agencies and researchers to attend to the public's interest in understanding, identifying, and being informed about risks beyond the personal scope.

Engaging with Public Risk Speculation: Opportunities and Challenges

The practice of risk speculation echoes multiple speculative approaches in the HCI community, such as critical design, futurescaping, design fiction, and speculative enactments [22,44]. Speculative approaches open up a space for discussion where people can debate potential ethical, cultural, social, and political implications, and form their own opinion about what kind of future they desire [21]. Speculative approaches can explore public perceptions of different futures before they happen [21]. Risk speculation shows how ordinary people as risk communicators were adept at using Reddit to brainstorm risks and risk management measures. Citizens' risk perception may not be arcuate and correct, or do not align with professional risk analysis [60], but is not necessarily or totally ill-founded. Rather, the reasonings are often grounded in situated knowledge and experience that can be valuable for public health research and practice.

Our study also highlights opportunities of participatory risk communication, where the public can be engaged as risk communicators so that public health authorities can solicit public views, understand public interest and concerns, the rationality and values behind the public's risk perception, and investigate issues that they may have overlooked (e.g., experiential and local knowledge). Furthermore, since risks and risk management measures affect the citizens' own lives, it is ethical to adequately include them in the decision-making process. Thus, it is valuable to encourage more dialogues between public health agency and citizens in risk communication.

However, such approach is not without challenges, and may have to be carried out cautiously and gradually. For example, public health agencies might lack dedicated social media personnel in communicating with citizens [64], lack of skills and training in social media [56,64], lack of a social media policy/guidance in place [56,64], or are concerned with liability issues [62]. For example, it is understandable that public health agencies might act on social media using serious, formal language in an objective tone with a careful attitude due to many practical reasons [29].

Considering both opportunities and challenges, we suggest that the ways that authorities engage with public risk speculation can take place at several layers with different degrees of institutional constraints. First, public health authorities can passively collect, analyze, and evaluate empirical data about the public's risk perception by making use of existing public discussions on social media platforms. For example, our study shows that social media data can reveal a large number of citizens' risk perception. Given that risk perception can be influenced by a wide range of factors (e.g., controllability, uncertainty, trust in institutions, media coverage, cultural traditions) [61,63,70,83], thus are not homogeneous, authorities can analyze and understand heterogeneous perception, preferences, and values of different populations. Second, public health agencies' existing websites can support interactions with citizens in ways such as online forums and virtual roundtables dedicated to different types of diseases, similar to the idea of citizen science in encouraging public participation in scientific research [37]. Lastly, social media platforms can support direct communication channels between public health agencies and ordinary citizens so that the former and the latter can interact on a regular basis about risks and policy decision-making about risk management measures.

CONCLUSION

In this paper, we presented a qualitative content analysis of risk communication and perception in the Zika outbreak. We highlighted the multidimensionality and speculative nature of risk perception. We discussed the implications of the multidimensional perspective for crisis informatics. We proposed to rethink authorities' existing model of risk communication, in favor of a participatory approach. More research can be done on risk communication on social media to understand the public's concerns, reasoning processes, and interests, to map out a fuller set of risks associated with different crisis types, and to reveal the role of risk communication in impacting citizens and institutions' informational practices during crises.

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