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Simulation-Based Experiments Reveal Differences in the Efficiency of Responses to Flood Warning Messages in Crisis

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Abstract: Evidence suggests that extreme flood events are increasing in frequency, severity, and expanding into regions previously thought to have low susceptibility. Increasing the flood risk landscape puts elevated pressure on effective and efficient flood risk and crisis communication. This study sought to understand how efficiently people were able to process and respond to a variety of different flood warning message treatments under simulated flooding conditions. To create this simulation-based experiment (a type of serious game), we developed a virtual neighborhood with an approaching storm, then provided participants with flood hazard messages. Participants could then select whether they wished to evacuate or prepare for the storm at home. Data were collected while participants experienced a series of these simulated events. A nationally representative sample of 370 participants completed the experiment. Our findings revealed distinctions in the efficiency of responses to different types of messages, as well as to years since experiencing a flood hazard event. Overall, results show promise for bridging research to operations in the domain of strategic crisis and risk communication, which may help protect lives and property in our ever-changing world.

Keywords — Decision-making, Flood forecasting, Flood inundation mapping, Risk communication, Serious games

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INTRODUCTION

Because of changes to our climate, and increasing pressure to force populations into vulnerable regions, flood crises are becoming more frequent and intense [1], placing an increased pressure on emergency preparedness and response. One aspect of this is communication and forecasting of events. Yet, flood forecasting is challenging with substantial uncertainties. Thus, flood hazard communication strategies must have the ability to be nimble and provide information that prompts quickly assimilated information and appropriate responses. Currently, the National Oceanic Atmospheric Administration (NOAA) is developing and testing a new modeling tool for the United States called Flood Inundation Mapping (FIM) which depict the expected spatial extent of flooding across a geographical region, and thus provide powerful information for emergency response and management. However, FIM forecasts do not include uncertainties (e.g., probability of occurrence), nor potential forecast error. Therefore, this information could be misinterpreted without sufficient understanding or background knowledge. An added complexity is that FIM will be available to the public (Currently NOAAs FIM products are available for approximately 10% of the U.S.). It is generally assumed that FIM will elicit rapid and appropriate responses by the public, however, aspects such as forecast uncertainty, as well as perceptions and experiences associated with flood hazards may influence their effectiveness.

Push Messages or Push Notifications are one of the crisis communication tools used to share critical flood hazard information messages, such as FIMs or text alerts, to a geographically targeted audience. These messages are being used to provide early warnings, however, they may lack key pieces of information, such as explanation of the problem, essential actions steps, and information as to why the message is important to the person receiving the message [2]. These factors can help determine if the message will prompt the desired decision-making process and actions.

Appropriately quantifying human decision-making processes is a challenging because multiple processes may drive decision-making, and determining the distribution of likely behaviors within a context is dependent upon the experience, attitudes, and perceptions of those making the decisions as well as the social-ecological context. To overcome many of these challenges, serious game experiments can be deployed to simulate conflict and allow for testing of hypotheses, especially in the context of decision-making and behavior under conditions of risk and crisis [3,4]. Using a serious game approach with a controlled experimental design is effective for risk communication research because it allows for collection of dynamic response data under simulated conditions without potentially harming the participants. To explore the efficiency of flood hazard messaging, we developed a type of serious game, a simulation-based experiment, that simulated a potentially flooded street-level environment, including sound, storm effects and flooding. A demonstration version of the game can be found at: https://segs.w3.uvm.edu/demos/CIROH-Flood-Evac1.6/

METHODS OR PROCEDURES

We developed our simulated environment using Unity (2021.3.18f1) (Figure 1). Experimental treatments were constructed to examine the responses to flood information along two axes: 1) flood hazard message type and 2) flood severity. Six flood hazard message types (detailed with the corresponding number on Figure 1) were used as follows: (1) a control text message, which was developed as an "as-is" text message by mimicking current text warnings, (2) a text message that added an internalization piece to the control text message, (3) a text message that added uncertainty in the flood severity, (4) a infographic control message, which was developed as an "as-is" infographic and captured from current flood hazard warning messages currently in use, (5) a FIM infographic depicted with text indicating a inundation estimate (6) a FIM infographic depicted as a GIF with uncertainty. Specifically, the FIM with uncertainty showed the forecasted inundation region, a "Low Estimate" and a "High Estimate". Each of these six warning messages was presented to the participant four times, once for each of

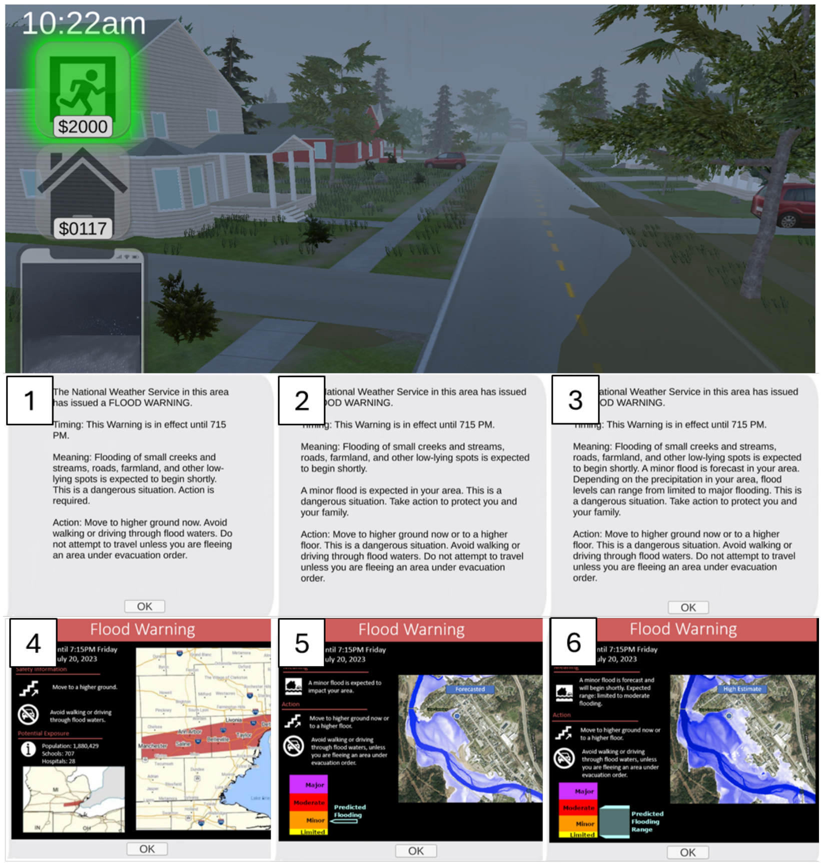

Figure 1 shows a screen grab of one of the simulation treatment rounds. One of the six message types would be presented with a forecast for one of four storm severities (Major, Moderate, Minor or Limited).

four flood severity forecasts: 1) Major Flooding, 2) Moderate Flooding, 3) Minor Flooding, and 4) Limited Flooding. Treatment order was randomized. Thus, over the course of the game, each participant experienced 24 flood event treatment rounds with each of the six message styles by each of the four flood severities.

Before the start of the experiment, participants viewed Institutional Review Board (IRB) approved consent materials (the experiment was approved by the University of Vermont IRB), then went through a detailed tutorial and two practice rounds. During the tutorial they were informed that the appropriate response if there was a Major or Moderate flood forecast was to Evacuate and that if there was a Minor or Limited flooding they should press the Prepare at Home button. After the tutorial participants started the data collection portion of the experiment which started with a view of their simulated neighborhood, and then, during the start of each treatment round the participant received an information in the form of a cell phone push notification containing flood hazard information. After receiving the push notification, they had a window of time to make a decision to either 1) Prepare at home or 2) Evacuate. Costs for these decisions were displayed on the graphical user interface (Figure 1). After a nine second grace period, costs for both preparing at home or evacuating would start to incrementally increase. To increase engagement and salience, participants were informed the money earned during the experiment would be translated into real world dollars, so the decisions they made during the experiment had real world consequences. Data collected during each round of play included the decision made by the participant, and how quickly the decision was made. This information was combined into a single normalized variable, labeled the Response Efficiency Index, with slow incorrect response coded near 0 and fast, appropriate responses coded towards 1. Additionally, several survey questions were asked of the participants at the end of the 24 rounds of game play. Included in the survey was the question "When was your most recent experience with flooding?" with categorical responses translated into an average number of years (e.g., "3-5 years ago" was coded as 4 years ago). If the participant had not experienced a flood, we coded Years Since Experiencing a Flood as the minimum of their age or 35 years. We used a mixed-effect logistic regression to examine associations between the Response Efficiency Index and message style treatments, flood levels and flood experience with participant as a random effect [5].

RESULTS

370 participants were recruited through Amazon Mechanical Turks, completed the experiment and provided evidence that they were making decisions based on the flood hazard information provided. We found significant differences between the message styles with the FIM infographic with Certainty showing the highest message response (Response Efficiency Index = 0.783), followed by FIM with Uncertainty (0.756), Improved Text with Certainty (0.753), Improved Text with Uncertainty (0.729), Control text "as is" (0.709) and lastly the control "as is" infographic (0.648). Substantial and significant differences are noted in the learning rates for these different messages with the "as is" infographic showing limited improvement over time, with others seeing substantial improvement. Results indicate a significant positive relationship between the Response Efficiency Index and Years Since Experiencing a Flood (z-value: 5.612, p<0.001). That is, participants response efficiency increased with increasing time since experiencing a flood event (Figure 3).

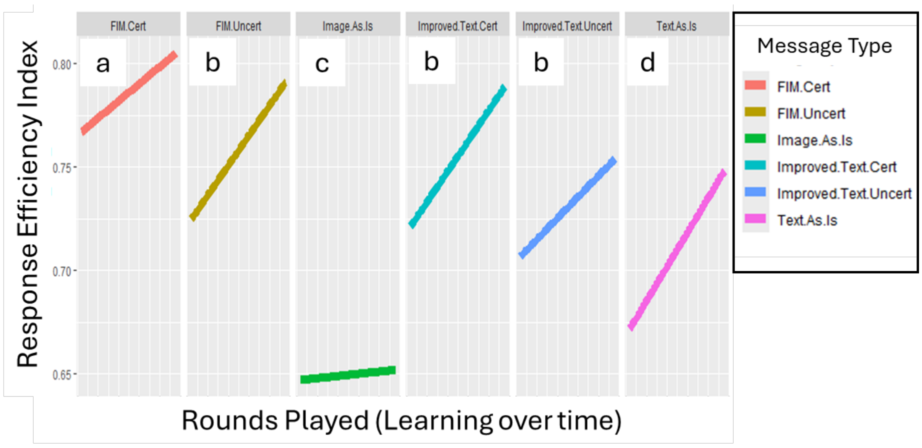

Figure 2 depicts participant responses to flood warning message types over the course of the experiment. Overall, the FIM with Certainty achieved the highest response levels with the "As is" infographic eliciting the worst responses. Significance letters mark least square mean differences between message style treatments at the alpha = 0.05 level. Slopes on each message type indicate consistent improvement in response efficiency over the course of the simulation-based experiment.

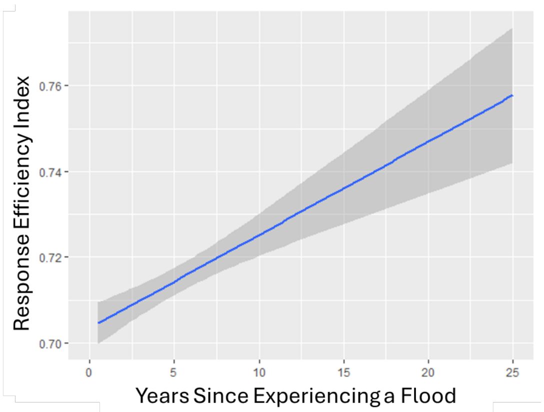

Figure 3 captures evidence for how personal experience with flood hazards, specifically time since last experiencing a flood, interacts with the speed and accuracy of responses with the Response Index improving with increased years since a flood experience (z-value: 5.612, p<.001).

DISCUSSION

These findings align with previous work that suggests that infographics, such as the FIM messages, have the potential to improve response efficiency over simple text or numbers [6]. However, this also serves as a reminder that poorly constructed or confusing infographics, such as the control infographic can lead to substantial response errors. Text messages that have improved content in terms of actions and internalization [2] resulted in improved response efficiency, indicating the potential for improvements in the emergency text messages that are currently in use. We noted substantial improvement in response efficiency over time for most of the message treatments (excluding the "as is" infographic message). This finding has direct implications for education or exposure to emergency messages in preparation for crises with an expectation that people will be able to learn how to interpret the messages with greater efficiency if they engaged with them in the past. However, this finding may be slightly contradictory because of the surprising result quantifying that years since experiencing a flood was positively correlated with better responses. That is, people with more recent flood experiences performed worse than those with more temporally distant experiences. The finding associating relatively poor performance with recent flood experience could be explained by a variety of factors, including a developed availability heuristic that may conflict with the flood message or a lack of trust in flood messages based on personal experience with message failure. Thus, additional complexities have been revealed which will prompt further research, such as determining what aspects of personal experience with floods may lead to positive and/or negative changes in response efficiency. Moreover, further research should explore interactions between experience, type of experience and efficiency of response to flood hazard information.

Understanding the relative distribution of responses to messages may allow for improved allocation of resources. For example, if an "as is" infographic was used to prompt emergency action, managers might be able to expect substantial message failure that could require substantial resources to counter. Further research could examine the effects of forecast inaccuracy or examine social effects on response efficiency.

CONCLUSION

With evidence strongly suggesting that flood frequency and severity are increasing [1] additional pressure is placed on effective risk and crisis communication to reduce costs potentially measured in lives lost. Here we used a simulation-based experiment to capture dynamic and evolving (learning) behavior, with results indicating that message style can dramatically shift response efficiency. However, additional work is warranted because we uncovered interesting behavioral responses associated with the number of years since people experienced flood events. Differences in efficiency in messages were found with FIM infographics consistently resulting in relatively quick and appropriate responses. The least efficient response was found in response to a currently used infographic, indicating that simply displaying information using graphical interfaces is not sufficient if critical features are not present. Thus, improvements could be made to current flood hazard crisis risk information because relative increases in response efficiency were noted for both graphical and text versions of flood hazard information. Learning rate was noticeably positive (excluding the "as is" infographic) which provides emphasis for education and preparedness programs. Emergency response personnel should be aware of these findings, especially when considering the new roll-out of FIMs (including a need to inform and educate the public about their usage). Here we show that differential responses to messages dependent upon message style and content with appropriate responses made approximately 20% more frequently when information was displayed with a FIM as contrasted with the control infographic. Communication efficiency can have substantial ramifications both directly on lives and property as well as indirectly on the allocation of resources by emergency responders. Here we show the potential effect of and need to develop messages that are quickly and accurately assimilated by the public.

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