Flood Warnings through a Mobile Navigation Application: Effects of Time Pressure and Flood Information Type

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Flood warnings are a means of risk communication that alerts the public to potential floods. The purpose of this study was to investigate factors that affected drivers' understanding and actions given a flood presented through a mobile navigation application. We examined the effects of time pressure and type of flood information on the planned actions of the participants. Participants were asked about their planned actions given one type of flood information (flood, no flood, flood of 2 inches, or flood of 4 inches) in a driving scenario either with or without time pressure. Our results indicated significant differences in participants' behaviors across the different flood information types, as well as a trend in the difference between the two time-pressure conditions. These results suggest that displaying the flood information is helpful to promote drivers' safe decisions to avoid the potentially flooded roadway, although detailed information may not always help.

INTRODUCTION

Successful risk communication for hazardous situations can prevent property damage and save lives. Properly informing the public about potential floods through flood warnings is a valuable way to implement risk communication. Flood warnings can vary in the amount of detail that is included in the warning. Some warnings tell the user the depth of the flood or where emergency resources can be found while others may only tell you that a flood is possible for your area (Leelawat et al., 2013). Flood warnings can also vary in how they are communicated to the public. Mobile applications are especially useful for conveying flood information to drivers. The objective of this study was to investigate factors that affect drivers' understanding and action to a flood warning given by their mobile navigation application in a written driving scenario.

Risk communication is a key factor in aiding people to make safe and appropriate decisions based on the risk at hand. The main objectives of risk communication are to inform and educate users about the risk in general, to encourage risk-reduction behavior and protective actions, to provide disaster warnings and emergency information, and to involve the public in risk management decision making and conflict resolution (Covello et al., 1986). Warning messages should answer seven questions that address these problems: who is issuing the warning, what is threatening, what exact geographical area is threatened, when is it coming, how probable is the event, are there high risk locations, such as people in automobiles that require special actions, and what specific protective actions should be taken (Drabek, 1999). Risk communication can come in various forms, ranging from warning labels on products to national safety alerts.

Flood risk communication aims to educate the public of a potential flood and to aid the public to make safe and smart decisions to protect themselves and their belongings from a possible flood situation. According to Mileti (1995), flood warnings should have a source, message consistency, accuracy, clarity, certainty, sufficient information, guidance, frequency, risk location information, and a channel of communication. Flood risk communication can also be conveyed through flood maps. Flood hazard maps should contain real-time information, water depths, the probabilities of occurrence, and should also use the color blue to represent water due to natural association (Hagemeier-Klose & Wagner, 2009). Liu et al. (2017) examined whether visuals improve the public's crisis and disaster information comprehension and found that maps only marginally improve message understandings. The majority of the information in a flood warning is carried by the warning itself rather than the map, but the map furthers the comprehension of information.

Flood risk communication can also be relayed through mobile devices. In fact, Cumiskey et al. (2015)

found that mobile services are the preferred means of warning communications for flash flood warnings. They also found that people preferred voice short messaging service (SMS) and interactive voice response (IVR) because of easier accessibility and understanding of the message. Specifically, for mobile devices, Leelawat et al. (2013) studied the different information that various weather mobile applications provided. They found that people want to download mobile weather apps that provide information related to flood warnings, flood-area monitoring, and flood road monitoring information. They also suggest that flood mobile apps should let users know where the flooded areas are and safe places that the users can evacuate to, and help users gather information to survive during flood situations.

Flash floods can happen quickly and without warning, catching people off-guard, especially when they are driving. It is not uncommon for drivers to be faced with a flooded roadway during a flash flood. The big question when drivers are faced with a flooded roadway is whether they will drive through it or not, and what factors influence their decision. The purpose of this study was to investigate factors that affected road users' understandings and actions given a flood warning, specifically, a flood warning through a mobile navigation application (i.e., Waze), in a written driving scenario. Currently, there are not many studies that investigate flood risk communication on mobile devices with a driving scenario. In this regard, there are also not many studies that give alternative routes, other than Coles and Hirschboeck (2020).

In the current study, participants were asked about their planned actions given one type of flood information (flood, no flood, flood of 2 inches, or flood of 4 inches) in a driving scenario either with or without time pressure. We hypothesized that participants would exhibit safe and avoidant behaviors (not keep the same route) when they learned that there was a flood of any depth on their route when compared to the no-flood conditions. If there was no flood expected on their route, then it was acceptable to keep the same route. We also hypothesized that participants who received the 4 inches of water depth flood warning would exhibit safer behavior than those who received the 2 inches of water depth flood warning, similarly to what Pearson and Hamilton (2014) found. They found that people were more willing to drive through the flooded roadway in the 20 centimeter scenario than in the 60 centimeter scenario. We expected participants to be less likely to keep the same route as the expected flood got deeper. We also predicted that participants with time pressure would drive through the flood (keep the same route) more often than those without time pressure because they had less options and time to make a safe decision.

METHOD

Participants

According to G*Power (Version 3.1), a statistical power analysis program (Faul et al., 2009), we needed a total of 179 participants in the analysis, using an alpha level of .05, a power level of .80, and estimating effect size of .25 for a moderate difference. A total of 207 participants were recruited through Amazon Mechanical Turk (MTurk). Participants met the following criteria: They lived in the United States of America and had a HIT approval rating of at least 95%. Participants were compensated $0.60 for taking part in the study. Participants who missed the single attention check in the survey were excluded from data analysis, resulting in 136 participants' data that were valid (age: M = 38.95, SD = 12.01; gender: 72 male, 62 female, 2 non-binary/third gender). These 136 participants resulted in a .66 achieved power from the analysis of variance (ANOVA) results.

Materials

Eight unique flood conditions, following a similar structure, were used for this study. These conditions were presented through a Qualtrics survey through desktop and laptop computers. Within these conditions, images taken from Waze were included to show the route that the navigation system planned out, as well as the warning that it conveyed about the flood. One of the eight conditions was randomly selected and presented to each participant.

At the beginning of the experiment, a simple auditory task (participants selected the word they heard, i.e., chair) occurred to ensure that the participants' speakers were on and could later hear the warning. Participants in all survey conditions were first placed in a location, either at home or on the road. The scenario then stated that the participant had a Honda Civic, a sedan car. For participants in the time-pressure condition, participants were told that they were to get directions to a restaurant to go pick up food in Waze. Once Waze mapped the route, a visual and auditory warning were presented to communicate the flood situation and possibly the depth of the flood water (see Figure 1). The auditory warnings ranged from 2 to 3 seconds in duration and were derived from a text-to-speech (TTS) voice online. The TTS warnings were created using Voicemaker.in, an online TTS converter which reads entered text using a synthesized voice. After the warning was presented, the participants answered several questions testing their understanding of the warning, how urgent the warning was to them, and what they planned to do. Once they answered all of these questions, the scenario told the participants that the navigation system had found an alternative route. They were then asked if they accepted the route that the system suggested for them or not. Lastly, they answered questions to measure their trust in the navigation system (Jian et al., 2000) and their demographic information (Kyriakidis et al., 2015).

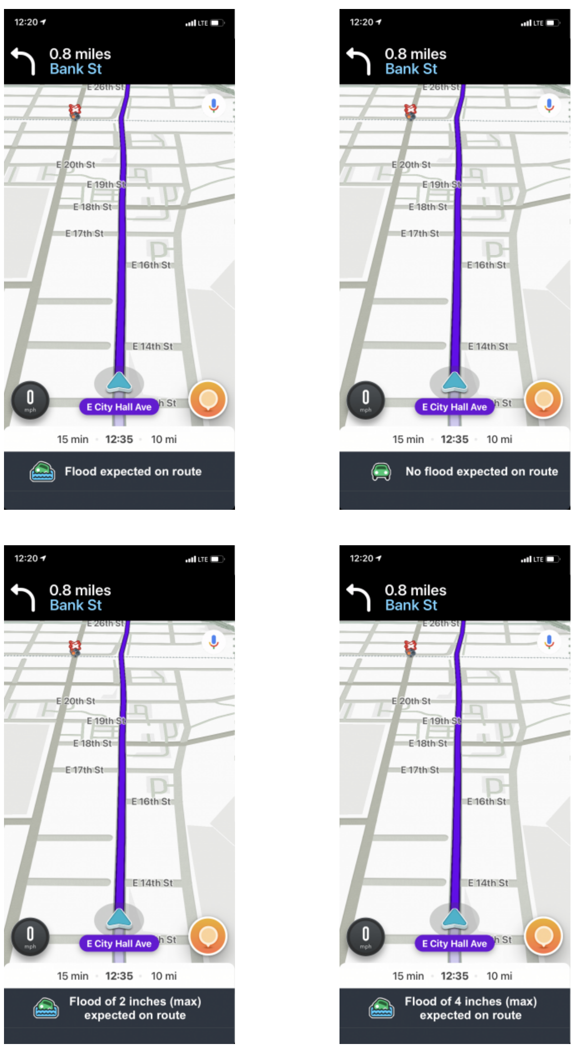

Figure 1. Waze Flood Warnings. From left to right, top to bottom: flood, no flood, flood of 2 inches, flood of 4 inches.

Design

The study was a factorial between-subjects design, so each participant was assigned to one of the eight scenario conditions. There were two independent variables, type of flood information (flood, no flood, flood 2 inches, and flood 4 inches) and the time pressure to take action (with time pressure, and without time pressure). As a result, there were a total of eight different scenario conditions, to which a participant was randomly assigned.

The first independent variable was the type of flood information given and with how much detail. This variable had four levels, two which communicated a binary categorization of the presence of a flood, and two which communicated different depths of the flood. For the former, the participant either received a warning that generally stated that there was a flood on their route (i.e., “There is a flood expected on your route”), or they received a warning that there was no expected flood on their route (i.e., “There is no flood expected on your route”). These two levels were abstract and contained the minimum amount of information that a warning would need in order to communicate if there is a flood or not. For the latter, the participant either received a warning that stated that there was a flood on their route that is 2 inches in depth (i.e., “There is a flood of 2 inches maximum expected on your route”), or that there was a flood on their route that is 4 inches in depth (i.e., “There is a flood of 4 inches maximum expected on your route”). These two levels provided more detail about the flood situation in addition to the general information that there was a flood. The depth of the flood conveyed the maximum number of inches of water on the roadways along the route.

The second independent variable was the time pressure to take action based on the warning given. There were two levels of time pressure. The participant either received the warning while still at home planning the trip a day before they departed to their destination, without time pressure, or while they were driving on the road in route to their destination, with time pressure.

The dependent variables for this study were the participant’s understanding of the warning, the action taken after the warning (continue with the original route, find a new route, wait for the flood to go away, go back home, stay at home, etc.), the action taken after Waze’s suggestion (continue with the original route, find a new route, wait for the flood to go away, accept new suggested route, go back home, stay at home, etc.) and their trust in the Waze system they used in the experiment as measured by the Checklist for Trust between People and Automation by Jian et al. (2000).

Procedure

Participants were recruited through MTurk during the 2021 Spring semester. The participants were individuals who had an MTurk account and voluntarily signed up for the study. Each participant was randomly assigned to one of the eight scenario conditions.

The participants first read and completed the consent form. They were then presented with a short audio clip and answered a question of what they heard to ensure that their sound was on so that they would be able to hear the auditory warning later in the experiment. They then read their scenario and viewed the accompanying images with their specific scenario condition. Once they received the warning in the scenario, they were directed to answer several questions testing their understanding and the urgency of the warning, as well as their planned actions. The scenario then continued to tell the participant that Waze had found an alternate route. Then the participant answered questions regarding their next actions again, whether they accepted the new route suggested by Waze or not, and their trust in the system's warning and new route suggestion.

After the last set of questions, the participant filled out demographic information as well as past flood history information (e.g., if they have ever driven through flooded roadways before or not). They were then given a unique code to enter into MTurk to receive compensation.

A single attention check question was included in this survey, embedded within the questions testing for understanding. The purpose of this attention check was to ensure the participants were reading the questions rather than spontaneously responding without thinking about what the question was asking. The attention check stated "Based on the scenario, where are you planning on going? For this question, answer *nowhere.*" If participants did not select the answer "Nowhere", their data would be excluded from the analysis.

RESULTS

A 2 (time pressure: with, without) x 4 (flood information: flood, no flood, flood of 2 inches, flood of 4 inches) between-subjects ANOVA was conducted to determine how each factor affected the type of action taken by the participant after receiving the flood warning (see Figure 2). The type of action was compiled by setting the option of "Keep the original route" equal to 1 and setting all other option choices equal 0. For a flood scenario, the 1 represents a risky or dangerous behavior while 0 represents safe or avoidant behaviors. Levene's test was significant, indicating that the variances were heterogeneous, $F(7, 128) = 9.46$, $p < .001$. The data also does not have a normal distribution (*Skewness* = 0.69, *Kurtosis* = -1.55). The main effect of flood information was significant, $F(3, 128) = 19.20$, $p < .001$, $\eta_p^2 = .31$. The results of a Tukey post-hoc analysis indicated that participants in the no-flood condition (M = 73.68%) were significantly more likely to keep the same route than the flood condition (M = 3.33%), $p < .001$, the flood-of-2-inches condition (M = 21.21%), $p < .001$, and the flood-of-4-inches condition (M = 28.57%), $p < .001$. Participants in the flood-of-4-inches condition tended to keep the same route more than the flood condition, but not significantly (Ms = 28.57% vs 3.33%), $p = .057$. There was no significant difference between the flood-of-2-inches condition and the flood condition, $p = .287$, and between the flood-of-2-inches condition and the flood-of-4-inches condition, $p = .871$. The main effect of time pressure was not significant, $F(1, 128) = 3.88$, $p = .051$, $\eta_p^2 = .03$. There was a tendency that participants with time pressure tended to choose the original drive more often than those without time pressure (Ms = 43.33% vs. 26.32%). The interaction between flood information and time pressure was also not significant, $F(3, 128) = 0.28$, $p = .839$, $\eta_p^2 = .01$.

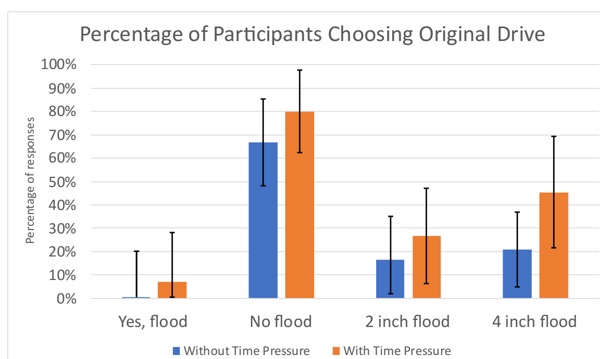

Figure 2. The Percentage of Participants Keeping the Original Route. Error bars are 95% CIs of the means.

DISCUSSION

Our first hypothesis, that participants would exhibit safe and avoidant behaviors by not keeping the original route in the flood conditions compared to the no-flood condition, was confirmed. Participants who were in the flood, the flood-of-2-inches, and the flood-of-4-inches conditions were all significantly less likely to keep the original route when each was compared to the no-flood condition. This result indicates that participants engaged in safe behaviors when they were warned of the expected flood on their route.

Our hypothesis that participants in the flood-of-4-inches condition would exhibit safer behavior than those in the flood-of-2-inches condition was not supported by the data. There was no significant difference between these two conditions. This result is inconsistent with what Pearson and Hamilton (2014) found, which may be due to the depth of the flood waters used or the difference in the depth of the flood waters. We used 2 inches and 4 inches while they used 20 centimeters and 60 centimeters, which roughly translates to 8 inches and 24 inches. It is likely that participants perceived both 2- and 4-inch flood to be safe to drive through.

Moreover, participants in the flood condition were less likely to keep the original route when compared to the flood-of-2-inches and the flood-of-4-inches condition. This means that participants engaged in safer behaviors when they were informed that there was flood but the depth of the flood waters was unknown. When simply stating that there is a flood, the message contains uncertainty as to how deep the flood is (e.g., it could be 2, 4, or deeper than 4 inches). Thus, it is reasonable that drivers tend to drive through the flood less often when the depth of the flood is not specified than when it is specified at 2- and 4-inch levels.

Our hypothesis that participants in the time pressure conditions would keep the same route more often than those in the no time pressure condition was not supported by our ANOVA result. In the ANOVA, the main effect was not significant, but had $p = .051$. Given that we did not have the number of participants as indicated in the power analysis, it is possible that this effect would be significant with sufficient power. If the effect of time pressure was significant, the mean data would have showed that participants without time pressure would display safer behaviors than those with time pressure. The more time and notice one has to make a decision about driving through a flooded roadway, the safer their decision is.

One limitation of the current study is low power and a small sample size. This low power is the suspected reason for why the main effect of time pressure was non-significant in the ANOVA. Another limitation of the study is that the driving scenarios were described to participants in written passages and images, which could be less realistic and might have influenced participants' decisions. Future studies can utilize a driving simulator to increase the external validity of the study.

In conclusion, whether the flood information is displayed can significantly affect drivers' decisions regarding a potentially flooded route. When presented with flood risk information, people are less likely to drive through floods; however, providing more detailed information might not necessarily aid in risk prevention. There is a tendency for time pressure to play a role in drivers' decisions, although it requires further validation. These results can help us design effective flood warnings and better understand drivers' behavior given a flood warning.

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