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User perception and interpretation of tornado probabilistic hazard information: Comparison of four graphical designs

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ABSTRACT

Effective design for presenting severe weather information is important to reduce devastating consequences of severe weather. The Probabilistic Hazard Information (PHI) system for severe weather is being developed by NOAA National Severe Storms Laboratory (NSSL) to communicate probabilistic hazardous weather information. This study investigates the effects of four PHI graphical designs for tornado threat, namely, "four-color"," red-scale", "grayscale" and "contour", on users' perception, interpretation, and reaction to threat information. PHI is presented on either a map background or a radar background. Analysis showed that the accuracy was significantly higher and response time faster when PHI was displayed on map background as compared to radar background due to better contrast. When displayed on a radar background, "grayscale" design resulted in a higher accuracy of responses. Possibly due to familiarity, participants reported four-color design as their favorite design, which also resulted in the fastest recognition of probability levels on both backgrounds. Our study shows the importance of using intuitive color-coding and sufficient contrast in conveying probabilistic threat information via graphical design. We also found that users follows a rational perceiving-judging-feeling-and acting approach in processing probabilistic hazard information for tornado.

1. Introduction

1.1. Probabilistic hazard information for severe weather

Meteorological disasters such as tornados have killed more than 10 thousand people, affected almost 13.8 million people and caused over 558 billion dollars in damage since 1980 (Centre for Research on the Epidemiology of Disasters, 2016). Protective actions are crucial to lessen devastating consequences of these disasters. Therefore, it is very important to effectively inform people about the threat, and ensure that they understand the information and engage in appropriate responses.

Currently, severe weather warnings are issued with the Warn-Gen System, which uses polygons to identify areas at risk of hazard impact in the next 45 min. While the weather threats develop dynamically, the current warning paradigm is static and deterministic. Once forecasters issue a warning, they cannot extend the front end of the polygon within the effective warning time, and the chance of encountering the threat is the same for all areas within the polygon (Coleman et al., 2011).

In order to make severe weather forecasting more effective and efficient and to avoid unnecessary warnings that result in economic loss and reduction of warnings credibility, NOAA's National Severe Storms Laboratory is developing the Probabilistic Hazard Information (PHI) system. This is a part of the vision of Forecasting a Continuum of Environmental Threats (FACETs; Rothfusz et al., 2014) to evolve the current deterministic severe weather watch and warning paradigm toward a continuous flow of information via probabilistic hazard information (PHI). This new system provides dynamically updated probabilistic hazardous weather information. In NOAA's hazardous weather testbed (HWT) for PHI, a graphical display is used to convey the likelihood of threat occurrence in areas being impacted by severe weather threats (Karstens et al., 2015).

Public response to severe weather warnings are directly related to the perceived risk (Mileti and O'Brien, 1992) and the risk perception is affected by the uncertainty inherited in the warning. Other factors, such as "color", "wording", "symbols", "auditory characteristics" of the warning, may affect the risk perception and

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should be taken into account for designing an effective risk communication tool (Wogalter et al., 2002).

1.2. Graphical design of PHI

Weather information can be presented graphically with particular shapes overlaid on a geographical map, which could either be a plain map or include weather radar data. The PHI system presents weather threats as a probabilistic threat swath (Karstens et al., 2015). In the PHI object, different regions in the swath represent different probability levels of threat occurrence (Karstens et al., 2015; Ling et al., 2015). Effective design should take a minimum amount of time to be accurately understood. In order to effectively communicate the probabilistic information, graphical design principles need to be considered carefully. Two main graphical design principles, including color coding and contrast, were taken into account in the PHI graphical design.

1.2.1. Color coding

The color of a design has an important role in perceiving it (Rogers and Groop, 1981). With regard to a severe weather threat, the assumption is that different color schemes elicit different levels of fear in people, which leads to different protective behaviors (Ash et al., 2014). Besides, different color schemes do have an effect on the time to cognitively process the information embedded in the visualization (Carter and Carter, 1981). Therefore, appropriate use of colors can increase the effectiveness of the warning while inappropriate use of color could lead to confusion and exacerbate the disaster (Keller and Keller, 1993).

A color code can involve variations of three attributes of perceived colors -hue, brightness, and saturation - or a combination of them. (Bodrogi and Khan, 2012). Based upon how color perception works in human mind, researchers have suggested different color schemes for different uses (Stauffer et al., 2015; Rogowitz and Treinish, 1996; Hagh-Shenas et al., 2007). Some examples include “iso-luminant qualitative schemes” for classification, single hue sequential color maps, multiple-hue sequential color maps for either increasing or decreasing data, and “diverging” schemes centered on a neutral value for data with two extreme values (Stauffer et al., 2015).

Since different regions in the PHI swath correspond to different levels of probability of tornado occurrence, multiple-hue sequential coloring is considered as an appropriate method of visualization. In this case, each color is associated with a certain level of probability.

A number of standards regarding color use and associated level of risk could be considered in choosing colors for PHI swath. The general perception is that red corresponds to danger, orange to warning, and yellow to caution (American National Standards Institute, 1991). Braun et al. (1995) confirmed the above categorization in their experiment on warning label design. In a study on warning design, Wogalter et al. (2002) found that red is perceived to be riskier than yellow and yellow riskier than green. Similarly, Leonard (1999) found that in warning designs, fatal risk corresponds to the color red, deadly to orange, danger to black, warning to yellow, caution to green, attention to blue, and notice to white. Using multiple-hue sequential color maps, one of PHI graphical design in this study - the four-color design was created, which uses red to indicate extreme likelihood of a threat, followed by orange, yellow and green indicating subsequent lower levels of the probability.

Another color coding scheme- single hue sequential color maps or color saturation, has been proposed as an effective way to depict uncertainty (MacEachren, 1992). In this method, saturation of color varies from dark hues for certain information to light hues for uncertain information. Because PHI swath conveys uncertainty in meteorological information, single hue sequential color map could be used as an appropriate design method to create PHI swath. Two PHI graphical designs in this study: red-scale and grayscale design uses this color coding method, which varies the color saturation to indicate different levels of threat probability.

1.2.2. Contrast

Another important factor to consider is the contrast between the display and its background (Sanders and McCormick, 1993). Carter and Carter (1981) found that the color difference between a target and its background directly affected search time and relative fixation rate. In a study on text displays, Wu and Yuan (2003) found that the contrast of colors between foreground and background plays an important role in reading speed and visual preference. Therefore, we plan to study human perception and interpretation of PHI information swath on different commonly-used backgrounds that produce different contrasts.

1.3. Research objective

The objective of the current study is to compare four probabilistic hazard information (PHI) graphical designs and investigate their effects on human perception and interpretation of probabilistic hazard information for a tornado threat. We want to study what type of PHI swath color scheme helps people to accurately recognize the probability of being affected by a tornado threat and in accordance with that probability, make a rational judgement, have appropriate level of fear, and engage in appropriate protective actions. A reference bar was used together with PHI graphical designs to assist users in making decision. Our goal is to determine an effective graphical PHI design that requires a minimum amount of time to be accurately understood.

2. Method

2.1. Participants

This study collected data from 36 people who were randomly recruited from the University of Akron. All participants had normal vision with no color blindness according to self-reports. Overall, participants were 61.11% males and 38.89% females with an average age of 28 years old (SD = 5 yrs). This sample was predominantly white (57%) but also included Asians (25%), African Americans (6%) and more than 11% from other ethnicity groups.

2.2. Experiment design

A within-subject design was used in this experiment. The independent variables were display background type (background) and the swath's design type (design). The response variables were the response time to each question measured in millisecond and the accuracy of the answers in terms of obtained scores.

Two types of backgrounds were used, including a geographic map and a geographic map with radar image. Geographic map is commonly used to show the geospatial reference of the weather information. A geographic map, which most probably was unfamiliar to participants in Northeast Ohio, was used as the background (Fig. 1). Radar is the basic tool for weather forecasters and users of weather information to interrogate weather conditions. Therefore, radar image was overlaid on a geographic map as another type of background for PHI designs (Fig. 2). We refer to the two types of background as “With Radar” (WR) and “Without Radar” (WOR) in this paper.