How Individuals Process NWS Weather Warning Messages on Their Cell Phones

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ABSTRACT

U.S. government officials are focusing their attention on how to deliver timely and effective warning information to the public, especially given the devastating weather-related events that have occurred in recent years. With the increase of cell phones (and in particular, web-capable smartphones), weather warnings sent through various cellular technologies represent one way for officials to quickly notify an increasingly mobile public. Cellular technology innovations also make it possible for officials to broadcast information-rich media like graphics to cell phones. Whether warning messages must include such ''rich'' media to be effective remains an open question. The current study investigates the effectiveness of National Weather Service (NWS) warning messages sent either in plain text or in text that includes a radar image of the storm. The research protocol was modeled after the interactive National Weather Service (iNWS) messaging service currently available to NWS core partners. In the study, participants read full-text NWS warnings of tornadoes or flash floods that either did or did not include a radar image of the storm. The researchers timed participants' ability to decide if a critical town was in the warning area, and then probed their understanding of the message content. Results show that participants' decision times to the town question did not differ between the graphic and no-graphic conditions. None of the other message content measures differed as a function of message condition. The results have potential implications for the federal government's new Wireless Emergency Alert (WEA) system, which, as yet, is limited to text-only warnings.

1. Introduction

Several devastating weather-related crises in the United States in 2011 and 2012 have highlighted how providing timely warning information to the public is important. One need only consider the lives lost and estimated damages in dollars to appreciate the full scope and severity of the problem. The series of tornadoes in and around Tuscaloosa, Alabama, on 27 April 2011 caused 1500 injuries, 64 deaths (NWS WFO 2012), and roughly $224 million in damage to housing in the area (Rupinski 2011). Similarly, the enhanced Fujita 5 (EF-5) tornado that struck Joplin, Missouri, on 22 May 2011 injured over 1000 people and killed 159 individuals (NOAA 2011, p. ii). Finally, the damage from high winds and storm surge from Hurricane Sandy along the East Coast in October of 2012 was in the billions of U.S. dollars and caused 131 deaths (Lott et al. 2012). In each of these instances, the National Weather Service (NWS) issued weather warnings, which were then redistributed by radio, television, weather radios, and in the case of the tornadoes, warning sirens.

Although some individuals do not always act on the warning messages they receive (NOAA 2011, p. 6), it remains critical that the NWS distribute accurate and timely information to the public about potentially hazardous weather situations like tornadoes and flash floods. With the technological advances of the last decade, the cell phone has become a vital piece of the warning puzzle (National Research Council 2011). Today, cell phones are ubiquitous in the United States. In December 2012, the wireless penetration in the United States and its territories reached 102.2% [the number of active units divided by the total population (CTIA 2011)]. Further, smartphone ownership (i.e., phones with mobile computing capabilities) reached 45% in September 2012, with the highest percentage (66%) seen among those aged 18–29 (Rainie 2012). Given that the NWS issues about 3500 tornado warnings each year (Sutter and Erickson 2010), public awareness of weather warnings could be increased by capitalizing on the cell phone, especially for those individuals who may not be near a television, radio, or computer. Even individuals who

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hear a tornado warning siren do not always take action (NOAA 2011), or they may delay their response (Hammer and Schmidlin 2002). The research literature has identified a number of nonmessage factors that influence people's likelihood to act on warnings. These factors range from demographic variables such as age, gender, and ethnicity to more personal factors such as previous experience with the hazard or fatalistic beliefs (Sorensen 2000). Given that receiving a warning on more message channels is typically associated with a higher probability of responding to the risk (Sorensen 2000), a text message appearing on a cell phone may be one more effective tool to help communicate the urgency of the message to the end user. Such a message might also be the first warning message that the user receives, thus allowing for faster notification.

Today, faster cellular networks, coupled with advances in both cell phone hardware and software, allow commercial weather services to ''push'' multimedia content to consumers' cell phones. In addition to a text alert, many providers include a hyperlink in the message so that users can access more detailed information. Tapping the hyperlink opens rich information, such as a radar image and a location-specific map with the watch or warning polygon displayed, as well as the full-text NWS warning message. The NWS has adopted this approach with its interactive NWS (iNWS). The iNWS is an experimental service for cell phones that is currently limited to NWS core partners (i.e., emergency management, government, and university officials).

Whether graphics are an important component of warnings and create more effective warnings is a relevant empirical question, given the federal government's new Wireless Emergency Alerts (WEA) initiative. [WEA was also known as the Commercial Mobile Alert System (CMAS), but its name was officially changed to WEA by Federal Communications Commission (FCC) Order 13-280 on 25 February 2013 (FCC 2013). An informative fact sheet is available at www.fema.gov/pdf/emergency/ipaws/cmas_factsheet.pdf]. WEAs allow officials to send text-based emergency messages to wireless providers, who, in turn, deliver these alerts (for free) to their subscribers' phones. Subscribers' phones do not need to be smartphones, although they must have software updates to receive the alert. WEAs are broadcast through a separate channel from the one that carries voice and text and, as such, will not be bogged down by traditional network congestion often seen during emergencies (BBC News 2012; Traynor 2008).

Three properties of WEAs are particularly relevant to the current study. First, imminent threat alerts, such as tornado or flash-flood warnings, are geographically targeted and therefore only sent to users whose phones are in the defined warning area. Second, by current regulation, WEAs must be 90 characters or fewer and do not include a hyperlink. This is designed to help prevent congestion (FCC 2008). A third and practical advantage of WEAs is that the alerts are received by travelers who may be in unfamiliar surroundings, yet immediately realize that they are in the warning area.

The lack of a hyperlink in WEAs, contrasted with the relative information-rich radar image and warning polygon included in the iNWS warnings, begs the question of whether graphics are a necessary component of an effective warning message. This empirical question was the basis for the experiment described below.

2. Literature review

Risk management scholars have conducted a wide range of studies to understand one's tendency to take action during an emergency [for a review, see Nagele and Trainor (2012)]. Two main emphases within this body of research focus on (i) aspects of effective message construction and (ii) factors that influence how individuals process and respond to warning messages. In terms of message construction, researchers know a great deal about what distinguishes a good warning message from a poor message (Sorensen 2000). For instance, effective warning messages should be specific (Quarantelli 1980; Perry and Lindell 1991). Specificity, here, includes proximity and timeliness—the affected area and how long that area can expect to be in danger—as well as the certainty of the event. Other important message criteria include (at a minimum) the components of severity, urgency, action, and location (Drabek 1999; Mileti and Peek 2000).

Regarding the issue of how individuals process warning messages, one important factor is the credibility of the message source, which is important to help verify the accuracy of the information (Fiedrich and Burghardt 2007; Perry and Lindell 1991). Moreover, as individuals seek to understand the message, they scan it for relevance. Here, individuals assess the perceived severity of the threat (Riad et al. 1999), including individuals' appraisal of their personal and familial risk (Mileti and Peek 2000; Perry et al. 1981). Indeed, personalization of risk is important (Mileti and Peek 2000) and providing location-specific information is effective to help one personalize his or her risk (Nigg 1987).

The warning and watch messages disseminated by NWS officials incorporate the important message components discussed above. Additionally, as we stated previously, the warnings disseminated by the NWS through its iNWS service include a radar image superimposed on a crude map, along with the warning message itself.

This is reasonable based on the commonsense view that graphics will provide added information. The use of graphics is also consistent with the risk management literature, as a radar image may effectively communicate the severity of an impending storm, at least for those individuals who understand that colors ranging from yellow to fuchsia indicate the potential for more severe weather (NWS 2012). The inclusion of a map should also help localize an individual, allowing for increased personalization of risk. Finally, a radar image from the NWS should also be viewed as highly credible, again arguing for the inclusion of a graphic in wireless warning messages.

Interestingly, however, the research on the influence of graphics on understanding weather information does not necessarily support the contention that ‘‘more is better.’’ For instance, Nadav-Greenberg et al. (2008) found that different types of graphics depicting wind speed uncertainty produced differential effects among novice weather forecasters’ (undergraduate meteorology students) reading accuracy, ratings of uncertainty, wind speed forecasts, and their likelihood of posting a high-wind warning. Generally speaking, Nadav-Greenberg et al. (2008) found that box plots produced superior performance compared to two different types of color-coded charts. Similarly, Hegarty et al. (2010) found that salience of a particular task-relevant dimension of a weather map (i.e., pressure isobars for detecting wind direction) only had an influence on performance after psychology undergraduates learned the appropriate meteorological principles. These two studies demonstrate that the *type* of graphic influences performance, with some graphics being more effective than others.

Alternatively, research has shown the pitfalls when a graphic does not depict the weather in a way that is helpful to the user (Schnotz and Bannert 2003) or when the graphic is too cognitively challenging (Peters 2008). Broad et al. (2007), for instance, found that many individuals (both the media and the public) have significant difficulty understanding the ‘‘cone of uncertainty’’ graphic that is often associated with a hurricane forecast. Especially challenging is understanding the track line depicting the forecasted path of the hurricane’s eye. Similarly, Savelli and Joslyn (2013) found that participants made more errors in their ability to explain a predictive forecast (i.e., one that forecasts a range of high and low temperatures) if it was accompanied by a visualization (22%) compared to a text-only version (6%). Joslyn et al. (2009) also found that their participants made many errors understanding the probability of precipitation, even when it was accompanied by a pie icon representing a corresponding probability. Finally, although novices and experts alike often express a preference for more complex weather graphics (e.g., graphics that include animations, realism, or 3D images), Hegarty et al. (2009) reported that participants’ accuracy decreased, and their response time increased, for inferring wind speed and pressure gradients as the task complexity increased. Hegarty et al. (2009) concluded that naïve cartographic intuitions are often incorrect. Or, as stated succinctly by Savelli and Joselyn (2013), ‘‘do not assume graphics help.’’

Given the uncertainty around the benefits (if any) of including graphics on understanding weather information, it is an open question whether the presence of a radar image would improve individuals’ ability to understand warning-related information. The decision-making literature suggests that a graphic might be beneficial. As Mileti and Fitzpatrick (1991) outline in their model of public risk communication, several informational factors influence one’s perception of risk. Three factors directly relevant to the present study include clarity, certainty, and location. It is reasonable to suggest that a radar image might increase one’s understanding of an immediate potential risk (i.e., clarity and certainty) as well as help one localize oneself with regard to the risk (i.e., location). Additionally, if the information added by a radar image is beneficial, then it might also increase the degree to which the receiver personalizes the risk and takes protective action (Mileti and Fitzpatrick 1991).

Given the possibility that graphics may aid in taking protective action, we designed an experiment that examined participants’ ability to understand relevant information in NWS warning messages. Specifically, we tested whether including a radar image with a full-text NWS tornado or flood warning influences the ability of the participants to make decisions about the message. We focused specifically on tornado and flash-flood warnings, given their rather short warning lead time compared to other severe events like a hurricane, flood, or blizzard. We created tornado and flash-flood warning messages that were either accompanied by a radar image or not, similar to what is available if one clicks on the link included in an iNWS warning message. We used a within-participants design such that every participant saw an equal number of messages with and without a radar image. We timed participants to see how long it took them to verify whether a specific town was or was not in the warning area. We also assessed our participants’ perceptions of severity, damage, specific damage, certainty of risk, personalization of risk, and likelihood to take protective action, based on the important message factors discussed above. Our hypothesis is given on the next page.

Participants who receive a NWS warning message that includes a graphic (a radar image and the corresponding warning polygon) will be able to make decisions about towns in the warning area more quickly and their ratings of the message's effectiveness at communicating the relevant information will be higher, compared to warning messages that do not include a graphic.

Interestingly, the clarity and effectiveness of NWS warnings themselves have been questioned (Jacks 2011). The public's ability to understand the difference between a watch and a warning is also problematic (Mitchem 2003; Sherman-Morris 2010). Nevertheless, warnings distributed by the NWS, in partnership with various media, are the foundation of most weather alerts received by the public (Golden and Adams 2000). As such, NWS warning messages represent a reasonable starting point to investigate the effectiveness of graphics on a warning message.

3. Method

a. Participants

The participants were undergraduates at a Pennsylvania university enrolled in psychology or communication courses, who received either course extra credit or eight dollars as compensation. All participants had normal or corrected-to-normal vision. Twenty-six undergraduates (mean age 20.35 years; range 18–30), 13 of whom were female, participated in the experiment.

b. Materials

We sampled 18 radar images and their corresponding warnings from archived NWS files. All of the warnings occurred outside of Pennsylvania so the locations would likely be novel to the participants, as would be the case for travelers in an unfamiliar state. We decided to choose locations that were likely unfamiliar to our participants to minimize potential effects due to differences in local geographical knowledge. We also chose unfamiliar locations because, in our view, a potential advantage of a wireless weather warning is its ability to warn individuals who are not familiar with their location and who may not be monitoring severe weather (as locals would be more apt to do). We chose storms that produced either flash flooding (nine storms) or F4 or F5 tornadoes (nine storms).[1] For the tornado warnings, we made every attempt to capture the tornado on the radar image by requesting images from the archived files that matched the time that the warning was issued. As the databases are incomplete, however, we cannot be certain that every tornado is actually reflected on our radar images. Table 1 shows the full text of a warning for a Michigan tornado that was used in the study, while Fig. 1 shows its corresponding maximized radar image.

As Table 2 shows, we combined the 18 warnings and their corresponding radar images into two lists. Two of the warnings (one tornado, one flood), which were text only, were for practice and were common to both lists. The remaining 16 warnings contained eight flash-flood and eight tornado warnings. Radar images accompanied half of the warnings, such that there were four flash-flood warnings with a radar image, four without a radar image, four tornado warnings with an image, and four without an image in each list. The warnings were counterbalanced across the two lists such that the warnings in list 1 that included a radar image did not include a radar image in list 2. Similarly, the warnings in list 1 that were text only included a radar image in list 2. Note that across both lists, the warning texts were identical. Some warnings simply included a radar image and some did not. In other words, the flash-flood warning for Edmond, Kansas, included both the warning text and a radar image in list 1 but included only the warning text in list 2. The average warning length was 1042.9 characters for the tornado warnings (range 916–1302) and 1651.4 characters for the flash-flood warnings (range 963–3184).

The warnings that we created are similar to those distributed through the iNWS system, and therefore represent one type of content-rich message that could be pushed to a smartphone. Although the future direction of NWS warnings (like WEAs) is that they will be narrowly targeted to only those phones within the warning's polygon [known as *storm-based warnings*; for a review, see Nagele and Trainor (2012)], most cell providers still broadcast the warnings at a county level (Gerber 2012). This means that individuals who may be driving nearby, but who are not actually in the warned area, could receive a warning.

NWS warning messages have a consistent format, which allows readers (after some practice) to locate specific types of information. As the example in Table 1 shows, the event type (i.e., tornado or flash flood) and warning time are listed first, followed by the affected area and the warning expiration. This information is followed by additional text that expands upon the warning and provides more specific information. This additional information includes the specific area(s) of the event, along with suggested courses of protective action. Therefore, based on the elements of effective warning message design and processing discussed

[1] The reader can contact the first author for further details on how the researchers constructed the graphic storm and radar images.

TABLE 1. NWS tornado warning message issued on 8 Jan 2008. Note: Approximately 17 lines could be seen on the phone's screen at once; users scrolled through the message with their fingers. The severity, urgency, and certainty information is indicated by bracketed comments immediately following the respective information.

WFUS53 KGRR 080003 CCA
TORGRR
MIC121-080045-
/O.COR.KGRR.TO.W.0001.080108T0000Z-080108T0045Z/
BULLETIN–EAS ACTIVATION REQUESTED
TORNADO WARNING. . .CORRECTED
NATIONAL WEATHER SERVICE GRAND RAPIDS MI
700 p.m. EST MON JAN 7 2008
THE NATIONAL WEATHER SERVICE IN GRAND RAPIDS
HAS ISSUED A
* TORNADO WARNING FOR. . .
MUSKEGON COUNTY IN WEST CENTRAL MICHIGAN
* UNTIL 745 p.m. EST
* AT 656 p.m. EST. . .NATIONAL WEATHER SERVICE DOPPLER RADAR INDICATED A
SEVERE THUNDERSTORM PRODUCING A TORNADO [severity]. THIS STORM WAS LOCATED 20 MILES SOUTHWEST OF ROOSEVELT PARK. . .OR ABOUT 20 MILES WEST OF GRAND HAVEN. . .AND MOVING NORTHEAST AT 50 MPH. THIS STORM HAS A HISTORY OF PRODUCING TORNADOES OVER SOUTHEAST WISCONSIN [urgency].
* THE TORNADO WILL BE NEAR. . .
ROOSEVELT PARK AND MUSKEGON BY 720 p.m. EST
FRUITPORT BY 725 p.m. EST
RAVENNA BY 735 p.m. EST [certainty]
THE SAFEST PLACE TO BE DURING A TORNADO IS IN A BASEMENT. GET UNDER A
WORKBENCH OR OTHER PIECE OF STURDY FURNITURE. IF NO BASEMENT IS
AVAILABLE. . .SEEK SHELTER ON THE LOWEST FLOOR OF THE BUILDING IN AN
INTERIOR HALLWAY OR ROOM SUCH AS A CLOSET. USE BLANKETS OR PILLOWS TO
COVER YOUR BODY AND ALWAYS STAY AWAY FROM WINDOWS.
A TORNADO WATCH REMAINS IN EFFECT UNTIL 200 a.m. EST TUESDAY MORNING
FOR SOUTHWESTERN MICHIGAN.
LAT. . .LON 4339 8604 4337 8602 4331 8603 4330 8598
4319 8591 4312 8614 4312 8628 4322 8636
4327 8637
TIME. . .MOT. . .LOC 0000Z 242DEG 44KT 4309 8657

earlier, we devised a list of queries for our participants that included one question and six ratings common to every storm and warning. We designed the question to mimic a situation that travelers would encounter if they were in an unfamiliar state and received a weather warning on their smartphone. The question always took the form ''Is [town name] in the warning area?'' All towns that were in the warning area (half of them) were specifically mentioned in the text warning (and in the case of tornado warnings, the towns were listed as in the path of the tornado) and appeared on the map within the polygon. We reasoned that the time taken to decide whether a specific town was or was not in the warning area would be a reasonable measure of whether including a map and a warning polygon helped our participants locate the storm, compared to a text-only condition. We viewed this task as a reasonable analog of a judgment a traveler would need to make if he or she were traveling through the area and needed to determine the immediate relevance of the warning. A traveler who found herself driving near a town listed in the warning would likely want to know so she could take immediate protective action. We therefore timed participants' responses. Reaction times are a common method used in experimental psychology to measure ease of processing [for a review, see Meyer et al. (1988)]. In our study, longer responses would be indicative of greater difficulty locating the town and, therefore, more difficulty in using the information in the warning.

The six ratings that followed the town question assessed information that NWS officials typically include in all of their warning messages: severity of the risk, certainty of the event, urgency of the warning, specific advice about effective protective actions, and location of the event. These ratings asked each participant to gauge their agreement level on a five-point Likert-type scale to determine whether the presence or absence of the radar image influenced the perceived magnitude of the weather event and participants' likelihood to take appropriate action. Although NWS warning messages do not typically include information about potential damage, we thought it reasonable to

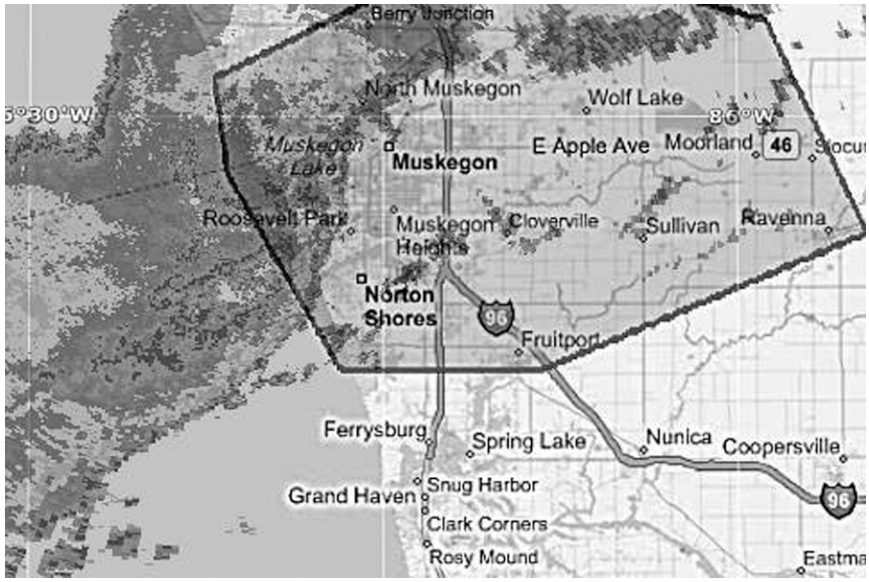

FIG. 1. Screenshot of the maximized radar image and its warning polygon for the tornado warning shown in Fig. 1.

include two questions on perceived damage in an attempt to assess whether warning recipients combine information about perceived severity and urgency to make inferences about potential damage. The question and ratings are shown in Table 3. Rating 5 (personalization of risk) and rating 6 (protective action) are particularly relevant for understanding how well individuals are able to assess the warnings. Note that all six of the ratings assess our participants' *perceptions* of risk based on the content of each warning; the warnings are not an assessment of actual storm risk. Although NWS warnings are typically issued at levels smaller than a county (e.g., storm-based warnings), many individuals still receive these warnings but never actually experience the weather event. For this reason, we thought measuring perceptions of risk was appropriate. As a final question presented after our participants responded to all 16 weather warnings, we queried each participant's preferred warning message type—a text message or a multimedia message.

We also wrote a brief passage for each participant to read as a measure of his or her reading speed, which we used as a covariate in our data analyses. This is an established method in the discourse processing literature (Hausfeld 1981; Roberts and Felser 2011). The passage discussed the difference between how psychologists define reinforcement and punishment. It was 146 words long and its Flesch–Kincaid readability index score was 8.35, which corresponded to approximately an eighth-grade reading level. The readability of the passage was considerably easier than that of the 18 NWS warning messages, which was 11.2 (comparable to an eleventh-grade reading level). To ensure careful reading, we also included a true/false question after the passage.

c. Procedure

We tested participants individually in sessions that lasted about 45 min. Each participant used an iPhone to

TABLE 2. List of towns and messages used in list 1. Note: Text-only messages in list 1 included both text and radar in list 2; text-only messages in list 2 included both text and radar in list 1.

	Town listed in		
Town/state	Message type	Warning area?	NWS warning
Practice 1, Afton, IA	Text	Yes	Tornado
Practice 2, Corolla, NC	Text	Yes	Tornado
1. Postell, GA	Text	No	Tornado
2. Edmond, KS	Text + radar	Yes	Flash flood
3. Stern, FL	Text	No	Flash flood
4. Redlands, CA	Text + radar	No	Flash flood
5. Strum, WI	Text + radar	No	Tornado
6. Spanishburg, WV	Text	Yes	Flash flood
7. Point Clear, AL	Text	Yes	Tornado
8. Blanks, LA	Text	No	Flash flood
9. Franklin, TX	Text	Yes	Flash flood
10. Carlisle, IN	Text + radar	Yes	Tornado
11. Eldersburg, MD	Text + radar	No	Flash flood
12. Elsmore, KS	Text	Yes	Tornado
13. Hiawatha, IA	Text	No	Tornado
14. Elm Creek, NE	Text + radar	Yes	Tornado
15. Nunica, MI	Text + radar	No	Tornado
16. Camdenton, MO	Text + radar	Yes	Flash flood

TABLE 3. Question and ratings assessed for every storm warning. Note: Participants responded to the town question by pressing the Y or N key on the computer keyboard. Participants responded to the ratings by pressing a number from 1 (strongly disagree) to 5 (strongly agree).

Town question	Is [town name] in the warning area?				
Rating 1 (severity)	The weather event is severe.				
Rating 2 (damage)	The weather event will likely cause damage.				
Rating 3 (specific damage)	I know the specific damage the weather event is expected to inflict.				
Rating 4 (certainty)	The weather event is certain to happen.				
Rating 5 (personalization of risk)	I would contact my loved ones at home to tell them about the storm.				
Rating 6 (protective action)	The message includes specific information that I can use to help protect myself, my family, and/or my property.				
Rating scale for all ratings	1 Strongly disagree	2	3 Neither agree or disagree	4	5 Strongly agree

read the warnings and to maximize the radar images. A computer running E-Prime 2.0 software (Psychology Software Tools 2010) controlled the presentation of the questions, scored responses, and recorded response times. After providing informed consent, we provided participants an overview of the study and then answered any participant's questions about the research task. Each participant then answered two questions that asked about how many text messages (without graphics) and multimedia messages (including graphics) that they send daily. We did this to get an estimate of their use of text-messaging technology. Participants next performed the task to measure reading speed. We showed each participant how to turn on and open the phone, and then launch an application (''app'') called GoodReader (Good.iWare Ltd. 2010). We preloaded the reinforcement and punishment paragraph into the app. We then instructed the participants to open the app. When the researcher said ''Go,'' a button to start the timer was pressed. The participants were instructed to press the space bar after reading the story, which then presented a yes/no question on the computer screen. Pressing the space bar stopped the timer. Participants answered the question by pressing the corresponding Y or N key. Participants then performed a smartphone familiarity task to assess their ability to use the technology. We showed each participant how to launch and enter appointment information into the calendar app, and their ability to do so was timed using the procedure outlined above for the GoodReader app.

Next, participants read and responded to the 18 warning messages (2 practices, 16 experimental), randomly receiving either list 1 or list 2. Because message type was counterbalanced, participants receiving list 1 read a text-only warning first, while those receiving list 2 received a text + radar warning first. We preloaded the warnings into the iPhone text message queue and numbered the messages ''practice message 1,'' ''practice message 2,'' ''message 1,'' ''message 2,'' and so forth. Participants were instructed on the computer screen to open each message sequentially when the researcher said ''Go'' by tapping on the message to enlarge the message contents. Each message contained the complete NWS warning for the associated storm. For those warnings accompanied by a graphic, a minimized thumbnail of the radar image appeared at the end of the warning text. All messages spilled over into multiple screens (range of 5–16), requiring participants to scroll up or down the message by swiping the screen to see the complete message (and radar image, for those trials that included one).

When the researcher said ''Go,'' the space bar that started the timer was pressed. Participants opened the first warning message and scrolled down and saw the thumbnail image whenever it was available. Participants then answered the town question by pressing the appropriate Y or N key on the computer keyboard. Each keyboard response triggered the next rating. The six ratings were answered using a five-point Likert-type scale printed on the screen, and participants pressed the corresponding number on the keyboard. After responding to all seven queries for each warning, participants returned to the text message queue. Participants then proceeded through the remaining warnings in the same manner. After all 18 warnings were read and the questions answered, participants responded to the final question that asked their preference for a text or multimedia warning message. The researcher debriefed each participant about the purpose of the experiment, and then thanked each person for his or her time.

4. Results

Initially, we planned to analyze the data from all 16 experimental warnings. We had assumed that participants would know how to enlarge the radar image for those warnings that included an image. It turned out that for several participants this was not the case. After they first saw a radar image (message 2 in list 1; message 1 in list 2), the researcher asked those participants who did not enlarge the image why they failed to do so; every one of them stated that they either did not see the image or that they did not know how to enlarge it. The researcher then demonstrated how to enlarge the image without giving any further instructions so as not to bias their later likelihood of using the image. This concern was unwarranted from that point on since all participants maximized the thumbnail image whenever it was available. Given that we could not use the data from the first message with a radar image, we therefore based our analyses on only the final 14 messages, 7 that included a radar image and 7 that did not.

The measure that most directly assessed whether a radar image assisted participants to decide if a town was (or was not) in the warning area was the time to decide "yes" or "no." We therefore performed an analysis of covariance on the decision time data using each participant's GoodReader reading time as the covariate to control for differences in how long it took participants to read the NWS warning statements. We also divided the participants into two groups, based on the median time it took them to use the calendar app, as a categorical "smartphone familiarity task" predictor variable. The results revealed no significant differences in decision times between the warnings that included an image ($M = 40.44$ s; SD = 20.38) and the warnings that did not ($M = 41.50$ s; SD = 23.76); $F(1, 23) = 1.77$, $p = 0.20$. A similar analysis using accuracy to the town question as the dependent variable also revealed no significant differences between the image (0.89) and text (0.84); $F(1, 23) < 1.00$.

One potential explanation for the lack of decision time differences in the image and text conditions could be due to a general practice effect. It is possible that with repeated practice, our participants learned where to look in each message type to find the appropriate information upon which to base a decision, thereby learning to ignore the radar image. To rule out this competing explanation, we conducted two additional analyses. First, we reanalyzed the decision time and accuracy data for deciding whether a town was or was not in the warning area and compared the data for the first seven warnings to that of the second seven warnings. No significant effects were found for either the decision time or the accuracy data. Second, we again compared the town name decision time and accuracy data, but this time compared the image to text conditions for the first story and the last story. It is possible that differences as a function of condition may not have been present for the first story but may have been present for the last story. Again, no significant effects were found. In addition to ruling out practice effects, these analyses also show that respondent fatigue was apparently not a factor in performing what was clearly a long and complex task.

TABLE 4. Results from the t tests comparing the mean radar image and text ratings for the six warning components to one another. Note: All ns = 26. Ratings ranged from 1 to 5.

	Radar image	Text	Std dev	t	p
Rating 1 (severity)	3.79	3.78	0.42	0.06	0.95
Rating 2 (damage)	3.80	3.79	0.45	0.12	0.90
Rating 3 (specific damage)	3.13	3.12	0.59	0.09	0.93
Rating 4 (certainty)	3.79	3.74	0.35	0.81	0.43
Rating 5 (personalization of risk)	4.01	3.95	0.38	0.80	0.43
Rating 6 (protective action)	3.82	3.91	0.49	0.99	0.33

Next, we conducted a series of paired samples t tests on each of the six rating items, comparing the ratings of the warnings that included images to those that included just text. As shown in Table 4, none of these comparisons was significantly different. We then performed two additional t tests, specifically comparing responses to rating 5 (assessing personalization of risk) and rating 6 (assessing understanding of appropriate protective action) to a neutral rating of 3 ("neither agree or disagree"). We did this to assess whether our participants viewed the messages as helpful. Both of these analyses were significant and showed that the warnings *were* perceived as helpful: rating 5, $t(25) = -6.16$, $p < 0.001$; rating 6, $t(25) = -6.79$, $p < 0.001$. Interestingly, although responses to ratings 5 and 6 did not differ as a function of whether a radar image was present, the messages did appear successful at personalizing the risk and providing information about appropriate protective action.

It is also informative to note the relatively low ratings for the question about specific damage. We therefore performed a t test comparing responses to the specific damage question to a neutral rating of 3. This analysis was not significant, $t(25) = 0.87$, $p = 0.39$. Clearly, our participants did not feel as if the warnings were helpful for revealing information about specific damage that the weather event was likely to produce. This should not be surprising, given that information about specific damage was not included in the warnings.

Last, we compared the severity ratings to the text to the text + image warnings for each individual storm to see if there may have been a trend for *some* storm warnings to show a beneficial effect of the radar image on perceived severity. After using the Bonferroni correction procedure ($\alpha = .004$), only 1 of the 14 comparisons was significant: An Alabama tornado warning produced greater perceived severity when an image was included, $t(24) = 3.62$, $p = 0.001$. Inspection of the text and radar image of this warning does not reveal any striking differences compared to the other warnings. We therefore surmise that this one significant finding simply reflects a type 1 error (i.e., a significant difference that is actually due to chance variation).

5. Discussion and conclusions

The goal of this research was to study the influence (if any) of a graphic on an individual's ability to extract relevant information from a NWS weather warning sent to a smartphone. We found no significant differences between the graphic and no-graphic conditions for any of the questions or ratings that we measured. We also found few differences in the perceived severity ratings when the graphic and no-graphic conditions were specifically compared for each individual warning. The lack of a beneficial effect of graphics might seem surprising. However, as we previously noted, the literature on the influence of graphics on weather decision making is somewhat ambiguous. Also, as previously noted by Hegarty et al. (2009), naïve intuitions about what makes a graphic effective are often not accurate. Individuals might *think* that they want realistic graphics that are full of information, but whether those graphics actually aid interpretation of a weather warning message on a cell phone has not, to our knowledge, been previously investigated.

We should point out that the experimental task that we used was somewhat artificial, and that we cannot rule out the possibility that our participants may have adopted specific strategies for reading the warnings and responding to our queries. We note, however, that the lack of a significant order effect (i.e., comparing responses of the first seven warnings to the second seven warnings) shows that our participants did *not* get significantly faster or more accurate with additional practice. The lack of a practice effect lessens the likelihood that our findings are due to our participants learning task-specific strategies.

Our findings, while preliminary, have potential implications for how the government, specifically the NWS, communicates imminent threat-type messages to individuals who may not be near their homes. As we noted earlier, an iNWS message includes a hyperlink to a low-resolution radar image that accompanies the full NWS statement. This is similar to what is practiced by commercial weather providers, such as WeatherBug and Weather.com, who often condense the full NWS statement and send some version of this information to mobile users with an accompanying graphic image. Our results raise the question of whether a graphic is something that *must* be included in a warning message for that message to be effective. Tentatively, our results suggest that the answer to this question is no. Further studies with a larger sample should be conducted. Regardless, our research is the first to our knowledge to experimentally investigate the processing time required to make decisions in a text versus a text + graphics messaging condition.

As we mentioned earlier, the federal government is expanding its capabilities to communicate time-sensitive weather information to mobile audiences. As such, in June 2012, the NWS announced that it would begin delivering imminent threat-type messages through WEAs (Gizicki 2012). Recall that WEAs are limited to 90 characters. One practical limitation is the difficulty encountered trying to parse the lengthy NWS full warnings in 90 characters, such that messages still convey useful information concerning what is happening, location, time, sending agency, and probably most important, recommended action. For instance, Mitchell et al. (2010), in a preliminary study examining a WEA-like 90-character warning against longer NWS warnings, found that their participants preferred the longer warnings because the shorter warning included limited information.

Current WEA guidelines also prohibit sending hyperlinks and graphics to mobile users' cell phones. The fear is that in an emergency, users will search the web for more information or make a phone call, thus potentially crippling cellular networks (FCC 2008). The decision not to include hyperlinks is reasonable, but it does raise the question of whether excluding such information might impair an individual's ability to make an informed decision about the impending urgency and severity of the warned event. Intuitively, it makes sense that if individuals were to receive a warning about a tornado or flash flood, then they would seek additional information by going to the NWS's website (or the individual's preferred weather and/or media source) for more information. This intuition is borne out by research showing that one of the first reactions to receiving a warning message is to seek verification (Drabek and Stephenson 1971; Mileti and Fitzpatrick 1991). If a hyperlink were included in a WEA, then one likely candidate would be a link to the appropriate NWS radar image. Since WEAs for weather events originate from a local NWS office, and because radar links are included for iNWS alerts, it seems reasonable to assume that the NWS might include a radar hyperlink if the possibility were available.

As the public's awareness of WEAs increases, and given people's desire to seek additional confirmatory evidence (Drabek and Stephenson 1971; Mileti and Fitzpatrick

1991), the decision to omit a hyperlink potentially has critical implications and is directly relevant to our current study. As mentioned in the literature review, a graphic has the potential to increase both one's understanding of potential risk and the personalization of that risk. As our results show, however, the use of a graphic did not influence response times, accuracy, or judgments about the impending weather event. Our somewhat counterintuitive finding may be because of several factors. For instance, consider the response times. The mean reading and response times of 40.4 s for the "text + radar" and the 41.5 s for the "text-only warnings" are relatively long, given the simple nature of the yes/no question, and likely reflect two complementary processing difficulties. On the one hand, we intentionally used warnings from states other than Pennsylvania to mimic what occurs when travelers find themselves in geographic areas with which they are not familiar. It may be that our participants' unfamiliarity with the warning locations slowed their ability to use the map and its corresponding radar image effectively. As a recent 2006 survey has shown, a large percentage of young adults cannot find New York State (50%) or Ohio (57%) on a U.S. map, which lends credence to this point (GFK 2006). Conversely, as we mentioned earlier, the warnings themselves were quite long, as is common in complete NWS alerts. These messages would have taken a relatively long time to read, even if the participants learned where to look in the messages for the towns that were included in the warning areas. Contrast these average lengths with the 90-character limit in WEAs.

Clearly, however, there was nothing about the warnings that included a radar image that made their processing inherently more difficult than the text-only versions. This is seen by the nonsignificant differences between the two conditions in all the ratings. Except for the specific damage rating, all the ratings were in the high 3 s to low 4 s, which indicated agreement that the messages communicated useful information. Indeed, the fact that the responses to rating 5 and rating 6 were significantly higher than a rating of 3 indicates that the messages did successfully personalize the risk (rating 5) and communicate information about helpful protective action (rating 6). The relatively neutral rating for whether the messages gave information about expected specific damages may reflect the fact that message content is intended to focus more on protective action and less on expected outcomes. Future research in this area can help address these issues. Regardless, the results of the current study have important implications for how government officials,specifically the Department of Commerce (NOAA/NWS) and the Department of Homeland Security, communicate imminent threats to an increasingly mobile public.

Although our results show that the presence of the radar image did not facilitate processing among any of the variables we measured, it is an open question whether some other type of image may have been beneficial. Still, it *is* somewhat surprising that the radar image did not help, given the ubiquitous presence of radar images in modern weather-related media. Given this wide presence, it is an interesting challenge to imagine what sort of graphic might aid in communicating weather-warning messages. This is another topic that future research should address.

Another important caveat is that our results may be limited to only those individuals who are unfamiliar with their geographical location when they receive a warning message. Since we used locations from states likely unfamiliar to our participants, it is an open question whether individuals familiar with those locations would have performed similarly. Radar images might well be helpful to individuals who can quickly locate their position with reference to the warning polygon. If true, then ratings on dimensions such as severity and certainty may well differ when a warning includes a radar image compared to those warnings that that only include text. This is a question best addressed through additional experimental research.

Further, whether a 90-character message is sufficient to communicate critical weather events is still unknown. As we noted earlier, social science research has convincingly shown that most individuals engage in message verification behavior. As such, a 90-character message may not provide sufficient information and context about the source of the message and the severity of the event to promote immediate protective action. Given the likelihood that a WEA may be the initial warning message that the public receives, the message content is important as the first step in the message verification process. Nonetheless, the lack of a hyperlink may well prompt the receiver to launch a web browser to search for additional information, which will tax the cell networks.

The decision in the initial WEA guidelines to exclude a hyperlink may well be correct. As we have demonstrated, the presence of a radar image in and of itself does not appear to improve decision-making processes about the content of the message. A message that focuses more on what the individual should do to take protective action appears to be the prudent course of action.

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