Communicating Increased Risk: An Empirical Investigation of the National Weather Service's Impact-Based Warnings

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ABSTRACT

In 2014, following a Central Region pilot assessment, the National Weather Service implemented large-scale use of an experimental product of enhanced severe weather warnings known as impact-based warnings (IBWs). The overarching goal of these IBWs is to improve the threat warning process and motivate appropriate responses by using event tags and additional text that provides more specificity about the magnitude of the storm and its potential consequences. These IBWs are designed to be used by individuals in the field to make more effective decisions. Although qualitative research has shown overall satisfaction with IBWs (Harrison et al. 2014; Losego et al. 2013), little published experimental research has been conducted on these new enhanced warnings. The research reported here therefore empirically investigates the effectiveness of the new IBW experimental product. In three experiments, participants adopted the role of a plant manager and read both IBWs and non-IBWs. At three different decision points, participants made decisions about shutting down the plant and having employees shelter in place. The results of all three experiments show that the IBWs produced higher likelihoods of closing the plant and sheltering in place, but only after the additional IBW text (providing information about the hazard, source, and impact) was presented. Interestingly, participant background knowledge of tornadoes and severe weather had little impact on their shelter in place decisions. The results support the conclusion that the additional enhanced text in IBWs promotes a higher stated likelihood of sheltering in place, at least as measured by behavioral intentions.

1. Introduction

The months of April and May 2011 produced a series of severe storm events that spawned many destructive tornadoes. Over 200 tornadoes occurred during 25–28 April 2011, impacting five southeastern states and resulting in 316 deaths (NOAA 2011b). About 1 month later, a single EF5 tornado hit Joplin, Missouri, resulting in 58 casualties (NOAA 2011a). Beyond the significant and tragic loss of life, what made these two events especially noteworthy is that both were well-warned events, with significant lead times and critical and timely information distributed (Levitan et al. 2013).

As is standard procedure, extensive NWS service assessments were conducted after the two outbreaks. Notably, both assessments identified problems with some of the generic warning terminology used in the standard NWS products (NOAA 2011b). The Joplin service assessment also explicitly suggested that a more credible warning would be one that was ''impact-based more than phenomenon-based for clarity on risk assessment'' and would be ''easily understood and calibrated by the public to facilitate decision making'' (NOAA 2011a, p. 11).

The conclusions of the two 2011 service assessments, particularly the Joplin service assessment, along with the recommendations provided by the National Institute of Standards and Technology (NIST) final report of the Joplin tornado (Levitan et al. 2013) provided the major impetus for an experimental warning product that was first piloted by the NWS Central Region in 2012. The NIST report, in particular, highlighted the need for a warning process that significantly enhances public perception of personal risk and promotes a rapid and effective public response. Given this ''call to action,'' a new, enhanced warning product known as an impact-based warning (IBW) was designed with the specific intent to improve risk communication by using expanded and more specific wording concerning the

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hazard, source, and impact of the forecast storm that clearly identified potential threats (Hudson et al. 2013). Threat tags at the bottom of each warning were also included that succinctly identified the reason for the warning (e.g., ground spotter or radar indicated) and potential damage. Both of these enhancements were designed to make the warning information easier to use. The initial IBW pilot project began in five Weather Forecast Offices (WFOs) in the NWS Central Region and has since expanded to 46 offices in spring 2014. The goal is to have all WFOs using IBWs by 2016 (Hudson et al. 2015).

As a new weather product from the NWS, the evaluation of the implementation of IBWs and their success has been from a qualitative perspective, focusing primarily on end users' satisfaction. This research has generally found that users believe IBWs to be an improvement over the non-IBW warnings, with some caveats to be discussed in the next section (Losego et al. 2013; Harrison et al. 2014). To date, however, no experimental work examining the effectiveness of actual IBWs exists, and this void provided the impetus for the research reported here. A nice complement to the existing qualitative research would be provided by more experimentally driven, quantitative research. The results of such experimental research would also either provide important validation and support for the continued use of IBWs or provide motivation to potentially reevaluate and reconsider their use.

2. Literature review

a. Previous impact-based research

Evaluations of the IBW experimental product have been ongoing since its original inception in 2012. The scope of the evaluation research has assessed two issues: the physical science supporting the generation of threat tags and the social science addressing end users' satisfaction with the product. Considering the physical science research, a central question has been whether meteorological data support the use of tornado damage threat tags. The inclusion of a damage threat tag in an IBW was specifically designed to provide the forecaster's best estimate of the magnitude of severe damage. By design, most tornado warnings would not include a damage tag. The damage tag "TORNADO DAMAGE THREAT…CONSIDERABLE" would be used rarely and only when a forecaster had high confidence based on credible radar and ground spotter evidence that a tornado of a stronger variety was imminent or ongoing and the duration of the tornado was expected to be longer lived. Use of the threat tag "TORNADO DAMAGE THREAT…CATASTROPHIC" would be exceedingly rare and only when the forecaster had absolute certainty, based on direct observational evidence, that a tornado will strike (or is striking) a densely populated area (Hudson et al. 2015).

The main impetus of the physical science research has therefore been to see if there are particular environmental and radar attributes that are associated with greater tornado intensity that could then be used by forecasters to signal potentially greater risk. Recent work by Smith et al. (2015) suggests that this is indeed possible. Based on their analysis of over 4700 tornadoes from 2009 to 2013, Smith et al. found that conditional probabilities for EF2+ tornadoes are 55%–60% for storms with a peak rotational velocity of 60–69.9 knots (kt; $1\,\mathrm{kt} = 0.51\,\mathrm{m\,s^{-1}}$) and are 65%–70% for storms with a peak rotational velocity of 80–89.9 kt. Smith et al. (2014) suggested that forecasters could use the "considerable" threat tag for storms with a peak rotational velocity of $\geq$60 kt. Research by Entremont and Lamb (2015), using updated radar data, also found that strong or significant tornadoes (which could again prompt the use of the considerable threat tag) became increasingly likely when tornadic debris is lofted to 10 kft (1 kft = 304.8 m) or greater. Other recent research has shown credible relationships between radar signatures and tornado intensity (Kingfield et al. 2012; LaDue et al. 2012; Toth et al. 2013). Collectively, these recent findings are encouraging and suggest that the physical science can indeed assist NWS forecasters in more accurately predicting and warning tornado intensity.

Hudson and Perry (2014) have also shown that when a NWS forecaster does release a damage threat tag, it is correlated with a higher intensity tornado. Hudson and Perry examined the hit rate for tornadoes that were warned over a 2-yr span from the WFOs participating in the IBW project. As a useful baseline, Hudson and Perry report a 28% tornado warning hit rate since 2008. Of the 823 tornado warnings that were issued, 57 were released with damage threat tags. Of those 57 warnings, 37 resulted in an EF1 or greater tornado for a hit rate of 65%. Additionally, 74% of the warnings with damage threat tags were verified with a tornado, indicating that using a damage threat tag can be used as an indicator of forecaster confidence that a tornado will in fact occur.

The main focus of the research to be presented here, however, is social science based, and, as previously mentioned, the research conducted to date on end users' satisfaction with IBWs is encouraging. After the 2012 storm season, Losego et al. (2013) conducted an early evaluation of the IBW pilot project by conducting interviews and focus groups with NWS forecasters (WFs), emergency managers (EMs), and broadcast meteorologists (BMs). Their overall finding was that the EMs (and to a lesser extent, WFs) thought the IBWs were helpful, especially for members of the public. A follow-up evaluation of the IBW project was conducted by Harrison et al. (2014). They also distributed surveys and conducted interviews and focus groups among WFs, EMs, and BMs. Their results showed that all three groups thought that the IBW threat tags were 1) helpful in suggesting appropriate action and 2) added new, helpful information above and beyond the older tornado warning messages. Interestingly, when asked about limitations of IBWs, the WFs were more critical than were the EMs and BMs. WFs were more likely to mention inconsistency in the decision-making framework used to issue threat tags as a concern. WFs were also more concerned about the accuracy of the tags and whether or not the tags conveyed helpful information about potential impacts.

One recent experimental study is also informative concerning the potential beneficial effects of enhanced tornado warnings. Ripberger et al. (2015) examined the influence of consequence-based tornado messages on the likelihood of taking protective action. Ripberger et al. presented a survey to two large samples in two consecutive years, with each sample numbering over 3950 respondents. The experimental manipulation involved randomly presenting different tornado impacts to participants, with the damage roughly corresponding to damage associated with EF0 through EF5 tornadoes. Ripberger et al. found that as impact severity increased, so did the likelihood of engaging in some sort of protective action, at least up to an impact severity of ''significant.'' Once the impact was rated as severe or higher, however, sheltering in place decisions actually decreased, while decisions to leave one's residence continued to increase. Although Ripberger et al.'s results suggest that there may be a level at which the increasing severity of impacts produces diminishing returns, their results do show that differing levels of consequences can cause different behavioral intentions to shelter in place.

b. *Important risk communication variables*

At this juncture, it is important to note that the IBW experimental product was implemented based on the perceived need to do something immediately that would improve severe weather risk communication (Hudson et al. 2013). The traditional route of social scientists would have been to review the risk communication literature, identify potential improvements or enhancements, and then methodically test those alternatives to assess those that had the most promise. Of course, this is a more time-consuming approach, and immediate improvements were deemed necessary. It is important to note that some social scientists were instrumental in providing insight and guidance into the choice of words used in the enhanced warning text (Hudson et al. 2013). It should therefore not be surprising that the additional text added to IBWs that specifies particular hazard, source, and impact information is consistent with the risk communication literature. Hazard information provides specifics about the nature of the storm and predicted outcomes. An example would be ''HAZARD...DEVELOPING TORNADO AND QUARTER SIZE HAIL.'' Source information specifies whether the tornado was radar indicated or personally observed by a ground spotter, such as ''SOURCE...RADAR INDICATED ROTATION.'' Finally, impact information provides details about possible negative outcomes. An example would be ''IMPACT...MOBILE HOMES WILL BE HEAVILY DAMAGED OR DESTROYED. SIGNIFICANT DAMAGE TO ROOFS...WINDOWS AND VEHICLES WILL OCCUR. FLYING DEBRIS WILL BE DEADLY TO PEOPLE AND ANIMALS. EXTENSIVE TREE DAMAGE IS LIKELY.''

Although a thorough review of the risk communication literature is beyond the scope of this paper, it is instructive to briefly consider how the additional use of hazard, source, and impact text in IBWs, along with the use of threat tags, corresponds with the literature on risk communication and protective action taking. Research has shown that effective warning messages both must be as viewed as personally relevant and spur one to take protective action (Mileti 1999). An effective warning is also one that specifies the exact nature of the threat (Corvello 1998; Mileti and Sorensen 1990), increasing the likelihood that the receiver responds to it (Lindell et al. 1983; Lindell and Perry 1987) and personalizes it (Perry 1979). The increased specificity provided by the ''hazard'' portion of the IBW should therefore enhance personal relevance and potentially increase the likelihood the message recipient takes protective action. Receiving the message by itself, however, is often not enough to prompt protective action; confirming the message is also important (Lindell and Perry 2004, 2012), especially for tornado warnings (Sherman-Morris and Brown 2012). Additionally, observing and correctly interpreting environmental cues increases the likelihood of an appropriate response (Perry et al. 1981; Ketteridge and Fordham 1998). The IBW ''source'' information, which specifies whether the tornado is radar indicated or has been observed by a ground spotter, should therefore help provide confirmation of the weather risk and provide an important environmental cue.

In addition to confirming the risk, many individuals also want to know the storm's severity (Riad et al. 1999)

TABLE 1. Full text of Illinois tornado warning taken from archived Central Region tornado warnings and decision points are described in the text. Note that the enhanced IBW text and decision points are marked in bold. EAS stands for Emergency Alert System.

Illinois IBW
BULLETIN—EAS ACTIVATION REQUESTED
TORNADO WARNING
****Decision 1****
NATIONAL W EATHER SERVICE PADUCAH KY
832 p.m. CDT THU MAY 30 2013
THE NATIONAL WEATHER SERVICE IN PADUCAH HAS ISSUED A
* TORNADO WARNING FOR. . .
WESTERN FRANKLIN COUNTY IN SOUTH CENTRAL ILLINOIS. . .
NORTHEASTERN JACKSON COUNTY IN SOUTHERN ILLINOIS. . .
SOUTHEASTERN PERRY COUNTY IN SOUTH CENTRAL ILLINOIS. . .
* UNTIL 900 p.m. CDT
* AT 831 p.m. CDT. . .A SEVERE THUNDERSTORM CAPABLE OF PRODUCING A
TORNADO WAS LOCATED NEAR ELKVILLE. . .AND MOVING NORTHEAST AT 40 MPH.
HAZARD. . .DEVELOPING TORNADO AND QUARTER SIZE HAIL.
SOURCE. . .RADAR INDICATED ROTATION.
IMPACT. . .MOBILE HOMES WILL BE HEAVILY DAMAGED OR DESTROYED.
SIGNIFICANT DAMAGE TO ROOFS. . .WINDOWS AND VEHICLES WILL
OCCUR. FLYING DEBRIS WILL BE DEADLY TO PEOPLE AND ANIMALS.
EXTENSIVE TREE DAMAGE IS LIKELY.
* LOCATIONS IMPACTED INCLUDE. . .
DU QUOIN. . .ELKVILLE. . .SESSER. . .DOWELL AND ST. JOHNS.
****Decision 2****
PRECAUTIONARY/PREPAREDNESS ACTIONS. . .
TAKE COVER NOW. MOVE TO AN INTERIOR ROOM ON THE LOWEST FLOOR OF A
STURDY BUILDING. AVOID WINDOWS. IF IN A MOBILE HOME. . .A VEHICLE OR
OUTDOORS. . .MOVE TO THE CLOSEST SUBSTANTIAL SHELTER AND PROTECT
YOURSELF FROM FLYING DEBRIS.
&&
LAT. . .LON 3780 8918 3783 8938 3812 8931 3813 8904 3812 8903
TIME. . .MOT. . .LOC 0132Z 208DEG 33KT 3788 8922
TORNADO. . .RADAR INDICATED
HAIL. . .1.00IN
**** Decision 3****

Michigan non-IBW
BULLETIN—EAS ACTIVATION REQUESTED
TORNADO WARNING
****Decision 1****
NATIONAL WEATHER SERVICE DETROIT MI
732 p.m. CDT THU MAY 30 2013
THE NATIONAL WEATHER SERVICE IN DETROIT HAS ISSUED A
* TORNADO WARNING FOR. . .
WESTERN KALKASKA COUNTY IN SOUTH CENTRAL MICHIGAN. . .
NORTHEASTERN CALHOUN COUNTY IN SOUTHERN MICHIGAN. . .
SOUTHEASTERN BARRY COUNTY IN SOUTH CENTRAL MICHIGAN. . .
* UNTIL 800 p.m. CDT
* AT 731 p.m. CDT. . .A SEVERE THUNDERSTORM CAPABLE OF PRODUCING A
TORNADO WAS LOCATED NEAR BELLEVUE. . .AND MOVING NORTHEAST AT 40 MPH.
* LOCATIONS IMPACTED INCLUDE. . .
DE WITTE. . .BELLEVUE. . .KALAMO. . .DELTON AND ST. HELEN.
****Decision 2****
PRECAUTIONARY/PREPAREDNESS ACTIONS. . .
TAKE COVER NOW. MOVE TO AN INTERIOR ROOM ON THE LOWEST FLOOR OF A
STURDY BUILDING. AVOID WINDOWS. IF IN A MOBILE HOME. . .A VEHICLE OR
OUTDOORS. . .MOVE TO THE CLOSEST SUBSTANTIAL SHELTER AND PROTECT
YOURSELF FROM FLYING DEBRIS.
&&
LAT. . .LON 3780 8918 3783 8938 3812 8931 3813 8904 3812 8903

TABLE 1. (*Continued*)

TIME. . .MOT. . .LOC 0132Z 208DEG 33KT 3788 8922
TORNADO. . .RADAR INDICATED
HAIL. . .1.00IN
** Decision 3**

and the likelihood of personal risk. In fact, personalization of risk plays a crucial role as it has been linked to an increased likelihood of taking protective action (Mileti and Peek 2000; Perry et al. 1981) and it is also a critical component of Lindell and Perry's (2012) Protective Action Decision Model. In terms of IBWs, the "impact" information and the damage threat tags (if used) can be viewed as increasing personalization of risk due to the inclusion of very specific and likely damage outcomes. Providing location-specific information is also effective to help one personalize his or her risk (Nigg 1987). This sort of geographic information is already included in the current NWS warning with no changes made in the new IBWs.

The physical and social science research conducted to date on the effectiveness of IBWs paints a consistent picture—IBWs, at least as evaluated by the immediate end users and those issuing the warning, appear to successfully communicate increased risk. The physical science research suggests that environmental and storm attributes do exist that can help NWS forecasters distinguish more intense from less intense storms. The social science research also suggests that EMs and BMs, and to a lesser extent WFs, feel that IBWs are successful at effectively communicating increased risk. As mentioned previously, however, no experimental work examining the effectiveness of actual IBWs exists, and the research presented here was designed to address this issue.

3. Study rationale and specific hypotheses

The research reported here empirically investigates the effectiveness of the IBW approach. In three experiments, the present research examined the influence of the extra IBW text (e.g., the hazard, source, and impact information) on the ability of individuals to make protective action decisions. Given the laboratory-based nature of the experiments, behavioral intentions were used as an analog of actual behavior in a fashion similar to previous work in this area (Mason and Senkbeil 2015; Schultz et al. 2010). The use of damage threat tags was specifically not investigated because the intent of the present research was to examine the effectiveness of the IBW text, without the influence of damage threat tags. As stated previously, damage threat tags are only included for those tornadoes that are predicted to be especially damaging or long lasting. The most impartial assessment of the effectiveness of the IBWs would therefore be research that investigated the influence of the additional text without threat tags, as these types of IBWs are the most commonly released warnings (Hudson and Perry 2014).

In three separate experiments, participants read actual NWS warnings issued by the Central Region NWS offices participating in the IBW project. Some of the warnings were in their original enhanced IBW version, while other warnings were missing the IBW information (equivalent to the old warning messages). Participants adopted the role of a plant manager and read both types of warnings line by line. At three different points in each warning, participants made decisions about shutting down the plant and having employees shelter in place. The first decision occurred when the two versions of the warning (the IBW and non-IBW version) presented the same information. The second decision occurred after the hazard, source, and impact information was presented (which was absent in the non-IBW warnings). The third decision occurred at the end of the warning message. The only new information presented in the IBW warnings that was not present in the non-IBW warnings was presented in the final two lines. The first line described whether the tornado was radar or spotter indicated and the second line mentioned the size of hail associated with the storm. Three related hypotheses were tested:

> Shelter in place decisions will not differ between the IBWs and non-IBWs at decision point 1 because at that point the messages do not differ in content (H1). At decision point 2 (H2) and decision point 3 (H3), however, IBWs will produce higher likelihood ratings of sheltering in place, compared to the non-IBWs because the IBWs provide more specific and useful information.

Participants in experiment 1 were traditional university undergraduates. The participant pool in experiments 2a and 2b was expanded to both replicate the results of experiment 1 and to expand their generalizability. Experiment 2a used a larger and more diverse sample of university undergraduates, while experiment 2b used a sample of graduate students in an M.S. program in emergency management. The methodology of experiments 2a and 2b was identical to that of experiment 1 except that a web platform was utilized to collect the data.

4. Methods

a. Participants

The participants in experiment 1 were undergraduates at a Pennsylvania university enrolled in psychology or communication courses who received extra credit for their participation; 21 females (mean age 19.00 yr) and 19 males (mean age 20.24 yr) participated. The participants in experiment 2a were undergraduates at two campuses of a Pennsylvania university enrolled in psychology or communication courses who received extra credit for their participation. Because of the web-based nature of experiment 2a, in order to ensure that the participants were taking the task seriously and completing it without interruptions, the data were limited to only those participants who completed the task between 10 and 60 min to exclude potentially frivolous data. Data from five participants were discarded because they took over 60 min to complete the experiment. Of the remaining 88 undergraduates, 56 were female (mean age 21.16 yr) and 32 were male (mean age 21.22 yr). The participants in experiment 2b were graduate students at a Pennsylvania university enrolled in an M.S. program in emergency management who received course extra credit. Data from four participants were discarded because they took over 60 min to complete the experiment. Of the remaining 37 participants, 20 were female (mean age 29.85 yr) and 17 were male (mean age 30.94 yr).

b. Materials

The materials for all three experiments were identical. Four 2013 impact-based warnings were taken from archived Central Region tornado warnings. Control versions of these warnings were created by using actual county and town names from a different state using the same number of characters as the original message. For instance, an Illinois IBW became a Michigan non-IBW and "WESTERN FRANKLIN COUNTY IN SOUTH CENTRAL ILLINOIS" became "WESTERN KALKASKA COUNTY IN SOUTH CENTRAL MICHIGAN." Time stamps were also increased or decreased by 1 h. The materials therefore consisted of eight tornado warnings, four original IBWs (with no damage threat tags), and four control warnings with the hazard, source, and impact information removed. The full text of the Illinois/Michigan warning is shown in Table 1.

Instructions were also created that specifically outlined the decision task facing each participant following every NWS warning. Participants adopted the role of a plant manager of a manufacturing company, who has to weigh the competing demands of keeping production on schedule against the safety of the employees. The plant manager scenario was used in an explicit attempt to increase the realism of the exercise by making each participant responsible for the safety of the employees. The instructions are shown below:

> In this study, you will read some weather warnings from the National Weather Service (NWS) and be asked to make some decisions. You will play the role of a plant manager of a manufacturing company. The plant stays open 24 hours a day and is always staffed. The safety of the employees is your responsibility, but it's also your responsibility to keep the production line up and running if at all possible. One of the decisions plant managers have to make is whether to shut down production in a case of severe weather. Every once in a while, you will be interrupted and asked to make a decision about having your employees shelter in place (in other words, have them go to an interior safe location in the building). You will be asked to rate, on a 0 to 100 scale using whole numbers, your likelihood of shutting down the plant and having the employees shelter in place. A rating of 0 would be "I definitely would not shut down the line" while a rating of 100 would be "I would definitely shut down the line."

c. Procedure

Participants in experiment 1 were tested individually in sessions that lasted about 30 min. A computer running E-Prime 2.0 software controlled the presentation of the warnings and decision prompts, scoring of the responses, and recording of response times. After providing informed consent, an overview of the study was provided and participant questions were answered. Participants then read the eight warnings in a randomized order unique for each participant. Randomizing the story order for every participant negated any potential primacy or recency effects. Each warning was read line by line, with participants pressing the space bar to advance the text. At three different locations in each message, the participants were interrupted and asked to make a shelter in place decision for the plant employees. Decision 1 appeared after the first two lines; at this point, the two warning versions were identical. Decision 2 occurred immediately after the impacted locations were mentioned. For the IBWs, this decision occurred after the hazard, source, and impact information was presented; this extra information was simply omitted in the non-IBWs. Decision 3 occurred at the end of each warning. It is important to note that the "PRECAUTIONARY/PREPAREDNESS ACTIONS. . ." information appeared between decision 2 and decision 3, for both versions, as this information is already present in non-IBW messages. For every

TABLE 2. Tornado knowledge quiz.

1. Which of the following describes a tornado?
(a) A violently rotating column extending from a thunderstorm to the ground.
(b) A rotating funnel-shaped cloud rising from the ground and dissipating into a cloud.
(c) A violently rotating cloud rising from the ground that forms a cirrus cloud.
2. Which state below is not, at least partially, in tornado alley?
(a) Texas (b) Nebraska (c) Kansas (d) Iowa (e) Louisiana
3. For states in tornado alley, in what months do tornadoes generally occur?
(a) May through August (c) August through November.
(b) November through February (d) February through May.
4. What times are tornadoes most prevalent?
(a) Early morning and late afternoon. (c) Early morning and early afternoon.
(b) Late afternoon and evening. (d) Early morning and evening.
5. How much advance warning is typically given before a tornado strikes?
(a) 40 min (b) 13 min (c) 5 min (d) 20 min
6. Most tornados travel in what direction?
(a) NE (b) NW (c) SE (d) SW
7. Big cities and their tall buildings are protected from tornadoes.
(a) True (b) False
8. If possible, where should you seek shelter during a tornado?
(a) In the basement. (c) In the bathroom.
(b) Under a table. (d) Near a window.
9. What type of thunderstorms typically spawn tornadoes?
(a) Multicell storms (c) Supercore storms
(b) Multicore storms (d) Supercell storms
10. Which geographic location never experiences tornadoes?
(a) Lakes (b) Mountains (c) Rivers (d) Tornadoes can occur anywhere
11. Which of the following terms refers to the most urgent National Weather Service Statement?
(a) Watch (b) Alert (c) Warning (d) Advisory
12. Taking cover under freeway overpasses provides safe shelter from tornadoes.
(a) True (b) False
13. About how many tornadoes hit the U.S. each year?
(a) 75 (b) 300 (c) 600 (d) 1200 (e) 6500
14. Tornadoes are rated on a 0–5 scale using the Enhanced __________ scale.
(a) Tachihara (b) Scheffe (c) Yamamoto (d) Fujita

decision, participants entered a number between 0 and 100 on the keyboard and the computer logged the data. At the end of every warning, participants answered a four-option multiple choice question about information they had just read to ensure careful reading. Finally, after reading and responding to all eight warnings, participants answered a 14 question multiple-choice quiz to assess their knowledge of tornadoes and severe weather (hereafter referred to as "tornado knowledge"). The majority of the questions and their answers were derived from the website Severe Weather 101 (http://www.nssl.noaa.gov/education/svrwx101/tornadoes/). The tornado knowledge questions are shown in Table 2.

For experiments 2a and 2b, the experimental procedure, timing, and data collection were all controlled using Qualtrics software. The study flow was identical to that used in experiment 1, and the order of the NWS warnings was also randomized for each participant. Additionally, the EM graduate students provided the number of years they have been employed as a professional emergency manager (if any).

5. Results and discussion

For all three experiments, participants were divided into either low or high tornado knowledge based on a median split. The data for the three sheltering in place decisions were analyzed using a 2 (tornado knowledge: low vs high) $\times$ 2 (warning type: IBW vs non-IBW) $\times$ 3 (decision: 1, 2, or 3) mixed measures analysis of variance with warning type and decision repeated measures. There were no statistically significant main effects or interactions involving tornado knowledge. All tests for nonhomogeneity of variance were nonsignificant as well ($ps > 0.12$). As done by others assessing hazard perceptions (Perreault et al. 2014), in order to avoid potential problems associated with violations of compound symmetry and sphericity, Wilks' multivariate tests were used on the repeated dependent measures. Multiple comparison tests with Bonferroni adjustment were used to compare differences in estimated means for variables with significant results. Multivariate analysis of variance (MANOVA) outputs for all three experiments are shown in Table 3.

TABLE 3. MANOVA outputs for all three experiments.

Effect	Wilks value	Wilks F	Effect df	Error df	p	η_p^2
Experiment 1						
Decision	0.133	120.166	2	37	0.000	0.840
Decision × tornado knowledge	0.988	0.222	2	37	0.802	0.010
Type	0.465	43.708	1	38	0.000	0.535
Type × tornado knowledge	0.982	0.682	1	38	0.414	0.018
Decision × type	0.421	25.459	2	37	0.000	0.400
Decision × type × tornado knowledge	0.958	0.812	2	37	0.452	0.016
Experiment 2a						
Decision	0.219	151.84	2	85	0.000	0.756
Decision × tornado knowledge	0.946	2.416	2	85	0.095	0.046
Type	0.718	33.728	1	86	0.000	0.282
Type × tornado knowledge	0.995	0.405	1	86	0.526	0.005
Decision × type	0.593	29.148	2	85	0.000	0.292
Decision × type × tornado knowledge	0.963	1.627	2	85	0.203	0.019
Experiment 2b						
Decision	0.251	50.85	2	34	0.000	0.722
Decision × tornado knowledge	0.962	0.673	2	34	0.517	0.007
Type	0.552	28.462	1	35	0.000	0.448
Type × tornado knowledge	0.997	0.122	1	35	0.729	0.003
Decision × type	0.555	13.639	2	34	0.000	0.312
Decision × type × tornado knowledge	0.933	1.223	2	34	0.307	0.021

a. *Experiment 1*

The main effect of decision was statistically significant: $F(2, 37) = 120.166$, $p < 0.0001$, and $\eta_p^2 = 0.84$. Multiple comparisons revealed that the pattern of shelter in place ratings was decision 1 (26.42) < decision 2 (74.14) < decision 3 (87.02). The main effect of warning type was also statistically significant: $F(1, 38) = 43.71$, $p < 0.0001$, and $\eta_p^2 = 0.53$. Averaging over all three decision locations, decisions to IBWs (66.88) were greater than decisions to non-IBWs (58.17). For the purposes of the present study, however, the most interesting analysis is the warning type X decision analysis. This interaction was also statistically significant: $F(2, 37) = 25.46$, $p < 0.0001$, and $\eta_p^2 = 0.40$. A series of three dependent samples Student's t tests with Bonferroni correction were therefore performed comparing the shelter in place decisions for IBW versus non-IBW at each decision point. For decision 1, decisions to the IBWs (26.73) and non-IBWs (26.21) did not differ: $t(39) = 0.47$ and $p = 0.64$. For decision 2, shelter in place decisions to IBWs (83.06) were significantly greater than decisions to non-IBWs (65.21): $t(39) = 7.82$ and $p < 0.0001$. For decision 3, shelter in place decisions to IBWs (90.86) were also significantly greater than decisions to non-IBWs (83.18): $t(39) = 3.68$ and $p = 0.0007$. These data are shown in Fig. 1 and Table 4.

The results of experiment 1 showed that, for college undergraduates adopting the role of a plant manager faced with a tornado warning, the additional information in the IBWs produced higher likelihood decisions about sheltering in place compared to the non-IBWs. It is important to note that the ratings at decision 1 to the IBWs and non-IBWs were virtually identical and quite low. At decision 1, only two lines of information had been presented, and any decision could only be based on the fact that the NWS had issued a tornado warning. These low ratings suggest that the participants were taking the task seriously and support the first hypothesis that shelter in place decisions will not differ between the IBWs and non-IBWs at decision point 1. Hypotheses 2 and 3, which stated that the IBWs would produce higher shelter in place ratings at decisions 2 and 3, were supported as well. At decision 2, the IBW versions included the additional hazard, source, and impact information that was not present in the non-IBWs. This additional information clearly influenced the study participants because the average IBW rating was more than 18 points higher than the non-IBWs. This IBW advantage remained at decision 3, although at that point, only a small amount of additional information was in the IBW versions. Even with IBW decisions approaching ceiling, the average IBW rating was still a statistically significant 7 points higher than the non-IBW rating.

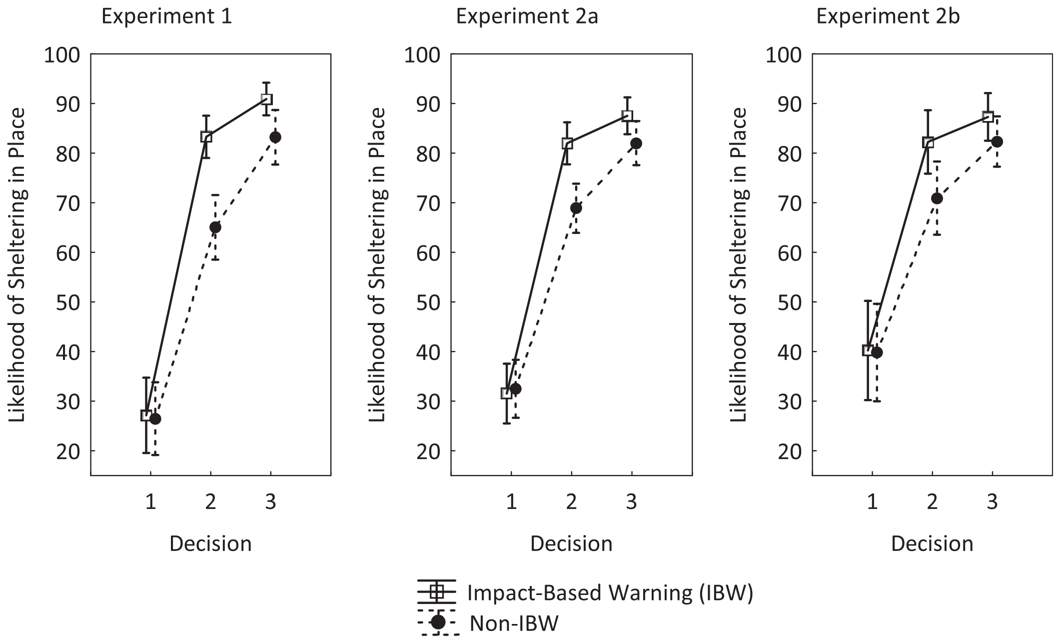

FIG. 1. Shelter in place ratings at each decision point for all three experiments.

Mean correct answers for tornado knowledge were 7.05/14, indicating that the undergraduates used in this experiment were not particularly severe weather savvy.

b. Experiments 2a and 2b

In both experiments, the significant main effects and interactions exactly mirrored those found in experiment 1. The main effect of decision was statistically significant: for experiment 2a, $F(2, 85) = 151.84$, $p < 0.0001$, and $\eta_p^2 = 0.76$; for experiment 2b, $F(2, 34) = 50.85$, $p < 0.0001$, and $\eta_p^2 = 0.72$. Multiple comparisons revealed that the pattern of shelter in place ratings was decision 1 < decision 2 < decision 3. The main effect of warning type was also statistically significant, with decisions to IBWs greater than those to non-IBWs: for experiment 2a, $F(1, 86) = 33.73$, $p < 0.0001$, and $\eta_p^2 = 0.28$; for experiment 2b, $F(1, 35) = 28.46$, $p < 0.0001$, and $\eta_p^2 = 0.45$. More importantly, the warning type X decision interaction was also statistically significant: for experiment 2a, $F(2, 85) = 29.15$, $p < 0.0001$, and $\eta_p^2 = 0.29$; for experiment 2b, $F(2, 34) = 13.64$, $p < 0.0001$, and $\eta_p^2 = 0.31$. For experiment 2a, dependent samples Student's *t* tests revealed that for decision 1, decisions to the IBWs (30.99) and non-IBWs (31.97) did not differ: $t(88) = 0.96$ and $p = 0.34$. For decision 2, decisions to IBWs (82.00) were significantly greater than decisions to non-IBWs (68.68): $t(88) = 13.31$ and $p < 0.0001$. For decision 3, decisions to IBWs (87.61) were also significantly greater than decisions to non-IBWs (82.12): $t(88) = 5.49$ and $p < 0.0001$. For experiment 2b, the pattern was the same. Decisions to the IBWs (40.39) and non-IBWs (39.52) did not differ: $t(37) = 0.34$ and $p = 0.74$. For decision 2, decisions to IBWs (82.45) were significantly greater than decisions to non-IBWs (71.06): $t(37) = 6.30$ and $p < 0.0001$. For decision 3, decisions to IBWs (87.64) were also significantly greater than decisions to non-IBWs (82.91): $t(37) = 3.41$ and $p < 0.002$. These data are shown in Fig. 1 and Table 4.

For experiment 2a, mean correct answers to the weather quiz were 4.42/14, indicating that the undergraduates in this experiment were even less weather savvy than those in experiment 1. For experiment 2b, mean correct answers to the weather quiz were 10.41/14, indicating that the EM graduate students in this sample were much more severe weather wise than the previous two samples.

TABLE 4. Mean responses to shelter in place decisions at three different decision points for each warning type.

Experiment	Decision	IBW	Non-IBW
1	1	26.73	26.21
	2	83.06	65.21
	3	90.86	83.18
2a	1	30.99	31.97
	2	82.00	68.68
	3	87.61	82.12
2b	1	40.39	39.52
	2	82.45	71.06
	3	87.64	82.91

To see whether the pattern of results differed as a function of participant background, two additional supplemental analyses were conducted. In the first analysis, data from experiments 2a and 2b were combined and reanalyzed treating experiment as a categorical variable to see if the responses from the undergraduates differed from those of the EM graduate students. This analysis showed that experiment did not interact with any other variable; the data revealed the same patterns as those shown in experiments 2a and 2b. The second analysis focused on the data from experiment 2b and included a categorical variable coding whether the EM graduate students had any years of professional emergency manager experience. Any response over zero was coded as a ''yes'' (19 out of 37; mean = 11.2). This analysis was done to see if those EM graduate students who had professional EM experience provided ratings that differed from the inexperienced graduate students. The only significant effect involving experience was a significant decision X experience interaction: $F(2, 34) = 6.56$, $p = 0.004$, and $\eta_p^2 = 0.17$. Simple effects revealed an experience effect only for decision 1; those students who had professional experience had higher shelter in place ratings (49.76) than those students without experience (30.05). Decisions 2 and 3 did not differ between the two groups.

The results from experiments 2a and 2b show a remarkably similar pattern to that found in experiment 1. Shelter in place responses again did not differ for decision 1, but for both decisions 2 and 3, the IBWs prompted higher shelter in place ratings than the non-IBWs. Interestingly, although the EM graduate students possessed significantly more knowledge about severe weather than the undergraduates and many also possessed a number of years of professional EM experience, the pattern did not differ between the undergraduates and the EM graduate students. Clearly, for both groups, the additional information in the IBWs prompted higher decisions about sheltering in place. Although the participants were adopting a hypothetical role of a plant manager tasked with making a shelter in place decision, the additional information in the IBWs clearly influenced that decision.

6. General discussion

The research reported here was designed to answer a straightforward question: can it be experimentally demonstrated that the enhanced IBW product promotes greater behavioral intentions of taking protective action? Based on the methodology used here, the answer appears to be yes. Across three experiments, using a hypothetical plant manager scenario, the additional information found in the IBWs produced greater behavioral intentions of sheltering in place, but only when the decisions were made after the enhanced text was presented (i.e., decisions 2 and 3). Prior to decision 1, the IBW and non-IBWs were identical, so the lack of difference in the shelter in place ratings, coupled with their low average rating, suggests that participants were sensitive to the lack of information in the warnings. These results support hypothesis 1. Hypotheses 2 and 3 were also supported by the finding of higher shelter in place decisions made to the IBWs for decisions 2 and 3. These findings also suggest that the participants were sensitive to the additional hazard, source, and impact information provided by the IBWs. The significant differences between IBWs and non-IBWs for decision 3 is even more impressive given that overall ratings for decision 3 were approaching ceiling.

Although IBWs were originally designed to be used with NWS partners, it is therefore interesting to note that both experiments demonstrated that even undergraduates were sensitive to the extra information in the IBWs. Additionally, tornado knowledge had no effect. Collectively, these results suggest that the added hazard, source, and impact information present in IBWs is not only understandable to a young student population (and one not particularly knowledgeable about severe weather) but also compelling, as least as measured by the shelter in place ratings.

Another interesting finding is that the pattern of responses of the EM graduate students did not differ from those of the undergraduates. One might argue that the superior knowledge of severe weather of the EM graduate students and/or their heightened familiarity with the various competing demands facing an EM when making a decision about whether or not to temporarily close a business might have influenced their shelter in place decisions. Although the supplemental analyses did find an effect comparing those graduate students with professional emergency management experience to those without such experience, the finding was limited to higher ratings at decision 1. No other effects of experience were found. That background knowledge and experience had little effect is actually encouraging and suggests that the enhanced text used in the IBWs is clear and understandable, regardless of target audience.

The results reported here complement those of Ripberger et al. (2015), who found that as tornado impact severity increased, sheltering in place decisions also increased, at least up to a ''significant'' impact. Ripberger et al. argue that their results support the concept of IBWs by showing that language that emphasizes increasingly strong tornado impacts has the potential to increase sheltering in place and saving lives. The present results also extend those of Ripberger et al. Using a more demanding task requiring three decisions to eight different warnings, and by using actual IBWs, the present results showed that the enhanced wording causally affected sheltering in place decisions.

It might be argued that the number of IBWs and non-IBWs used in the current experiments was small (four of each). Note, however, that the non-IBWs were, in fact, the exact same warnings as the original IBWs, with just a simple change in location and town/county names, providing an ideal control condition. Additionally, although the results are based on a much smaller sample than that used by Ripberger et al. (2015), the partial eta squared (η_p^2) effect sizes are quite robust (0.29–0.39).

One interesting question for future research to address is whether the results would be the same if a sample of professional EMs were tested, having a large number of years of experience making critical severe weather decisions. The current results, however, suggest any influence of background knowledge might be small. While the results of experiment 2b suggest that background knowledge could play a role, it may be limited to decisions made at early points in a warning message. Given their background, it may be that professional EMs would tend to view any tornado warning issued by the NWS as valid and therefore show a tendency to make higher shelter in place ratings based on the mere release of a tornado warning. Only additional research can answer this question.

7. Limitations

One potential limitation of the research design used in this study is that it only assessed behavioral intentions. Although measuring behavioral intentions is commonly used by social scientists when they study reactions to weather warnings (e.g., Schultz et al. 2010), it is valid to ask if intentions are related to actual behavior. Recall that the results of Ripberger et al. (2015) do suggest that behavioral intentions can be a useful proxy for actual behavior. Ripberger et al. assessed whether previous factors that have been shown to influence actual responses, such as having a plan (Nagele and Trainor 2012) and perceptions of risk (Kalkstein and Sheridan 2007), moderated their behavioral intentions. In two validation models, Ripberger et al. found that behavioral intentions did vary in the predicted way. Additionally, psychological research has shown statistically significant correlations between intended and actual behavior, as shown by Armitage and Conner's (2001) meta-analysis finding of $r = 0.47$. This body of work therefore suggests that the use of behavioral intentions is reasonable.

Another potential limitation concerns the use of the hypothetical scenario involving role playing a plant manager. It is reasonable to ask whether demand characteristics were created, such that the participants figured out the experimental manipulation and then acted as ''good subjects'' by providing ratings consistent with the hypotheses (Orne 1962; Nichols and Edlund 2015). Some might also argue that the task is somewhat artificial, especially for individuals with little or no experience in making decisions about the safety of others. The plant manager scenario was specifically used, however, in an attempt to increase the realism of the exercise, given the participant's responsibility for the safety of multiple individuals. Additionally, informal interviews with experiment 1 participants, asking if they could articulate the study's true intent, were done to inoculate against a potential charge of demand characteristics. Not a single participant was able to articulate that some of the warnings had additional information. This lack of awareness was not surprising given how immersed in the task they appeared to be—each warning was quite long (a minimum of 20 lines) and filled with unfamiliar county and town names that were in the path of the warned tornado. If the participants were indeed unaware of the IBW manipulation yet trying to be good subjects, then the decisions made at decision 2 and decision 3 should not have differed by warning type, yet they did. It therefore appears unlikely that the results are due to demand characteristics.

Yet another potential limitation concerns the use of the plant manager scenario and the level of risk one might be willing to assume as a function of employee oversight. On the one hand, it could be argued that a plant manager would be relatively risk averse while at work, given that he/she is responsible for the plant's employees. That same manager might be much less risk averse, however, while at home. The current study attempted to maximize risk aversion by intentionally placing each participant in responsibility over others. Nonetheless, future research could fruitfully investigate the role that responsibility for others plays (if any) on the relative level of risk one is willing to assume.[1]

Two final points deserve mention. First, the methodology used in the present study is not able to pinpoint which specific aspect of the IBWs contributed to their higher shelter in place ratings. It may be that all components of the expanded IBWs (hazard, source, and impact) are necessary and have a cumulative effect on prompting higher ratings. Alternatively, it could be that

[1] I thank an anonymous reviewer for bringing this potential limitation to my attention.

simply adding more information, regardless of content, is the mechanism behind the higher ratings. Yet another possibility is that the impact information heightened fear in the message recipient, with the other information playing little or no role. Each of these interpretations is plausible, and the current methodology cannot distinguish between them (or others). Nonetheless, regardless of the specific mechanism for the effect, the present study was able to demonstrate that some aspect of the IBWs did cause higher shelter in place ratings. Teasing apart the exact nature of this effect would be a fruitful avenue for future research.

A second issue concerns how best to evaluate the success of IBWs. The original impetus behind the implementation of IBWs was to provide a warning that promotes a rapid and effective public response. A legitimate question to ask, however, is what constitutes an effective response? It is possible, given the inherent uncertainty in severe weather events, that a tornado that was predicted to be an EF1 increases in strength to be one that is much stronger. In such a scenario, the protective action that was originally recommended in the IBW may turn out to not be the best advice. How would such an IBW be evaluated? Clearly, given the predictive nature of the entire weather warning process, any suggested protective action is only the forecaster's best guess given the information at hand. Equally clear is that IBWs cannot be faulted based on this criterion. This issue simply reveals the somewhat subjective nature of evaluating IBWs.[2]

8. Additional warning improvements

The present study's findings that IBWs produced greater behavior intentions to shelter in place, compared to non-IBWs, dovetail nicely with two other recent initiatives actively underway to improve the weather warning enterprise. One initiative, orchestrated by NOAA, is Weather Ready Nation (WRN; NOAA 2013). The emphasis of WRN is to unite the various entities involved in the weather warning process—the NWS, private sector entities, academia, state and local officials, the media, and EMs—to improve the entire disaster readiness, warning, and response process. The effort focuses particularly on building strong connections between operational and research communities with the ultimate goal of increasing community response and resilience to weather disasters. The effectiveness of IBWs, as demonstrated by the findings reported here, demonstrates the importance of such collaborations. The present study's findings are valuable because they independently validate the operational community's decision to implement IBWs.

The other initiative, known as Forecasting a Continuum of Environmental Threats (FACETS), is under the guidance of the National Severe Storms Laboratory (Rothfusz et al. 2014). FACETS focuses on the science side of the warning enterprise and aims to be the next generation severe weather watch and warning system. FACETS utilizes ''threat grids'' to communicate relative severe weather danger based on one's location and is aided by advances in satellite, radar, and ground observation technologies. Such advances clearly have implications for IBWs; improved storm path predictions should allow for better location and impact information in IBWs. The implementation of FACETS, along with the WRN initiative and IBWs, reveals the amount of emphasis placed by NOAA on improving the weather warning process.

9. Conclusions

Based on the results reported here, the decision by the NWS Central Region to begin immediate implementation of the IBW experimental product in 2013 was indeed wise. There was an urgent perceived need to upgrade the standard NWS warnings to provide more information about impact and potential consequences in the hopes that it would increase protective action-seeking behavior. The results reported here show that enhanced warnings can indeed increase the likelihood that a message recipient will take the suggested protective action. The ultimate goal, of course, is that the suggested protective action saves lives.

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[2] I thank an anonymous reviewer for making the two points above.

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