4.3 WHERE DO KNOWLEDGE GAPS EXIST? EVALUATING THE PUBLIC'S KNOWLEDGE OF TORNADOES, WARNINGS, AND PROTECTIVE ACTIONS

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[*]1. INTRODUCTION

Since 2010 U.S. researchers in the social and physical sciences have met three times to specifically promote development of a Weather-Ready Nation (WRN; www.nws.noaa.gov/com/weatherreadynation). The WRN goal entails increasing community resilience in response to extreme weather events. The research recommendations of the April 2012 workshop in Birmingham, AL were particularly focused on resilience to tornadoes because of the high fatality count in 2011. One theme of the April 2012 workshop recommendations was the need to understand the public's knowledge of tornadoes, tornado warnings, and protective actions in vulnerable regions of the country (Lindell and Brooks 2012).

Some research has been conducted in the past to determine knowledge of relevant terms such as *tornado warning* (e.g., Sherman-Morris 2010) and correct sheltering actions (e.g., Hoekstra et al. 2010; Minniear et al. 2011), though no comprehensive assessments have been completed. One comprehensive approach developed to understand lay knowledge of diverse hazards is based on identifying the hazard mental model, which is the conceptual representation of all relevant information about the hazard used to guide reasoning and decision-making (Bostrom et al. 1992). This approach can not only be used to assess what people know about the hazard but also to evaluate the accuracy of this knowledge and the gaps in critical knowledge by comparing lay knowledge to that of subject matter experts. Table 1 lists six categories of knowledge typically included in hazard mental models.

Recommendations from the 2012 WRN workshop (Lindell and Brooks 2012) also noted a need to assess demographic differences in tornado knowledge, particularly in vulnerable populations for which more assistance is needed from governmental and non-governmental organizations. One example of a vulnerable group is the population aged 65 and over, which is expected to double by 2050 (Ortman et al. 2014). Psychological research on age-related differences in use of prior knowledge in warning comprehension suggests that older adults may rely more than younger adults on their prior knowledge even when contradictory information is provided in the warning (Adams et al. 2011). Thus, assessing the mental models of older adults may be particularly important to developing community education programs for enhancing and correcting incorrect knowledge about tornadoes.

Table 1. Knowledge components typically included in hazard mental models (derived from Bostrom 2003).

Component	Description	Example elements
Identification	Describing hazard & warnings, including frequent terms	Tornado warning, wall cloud, Doppler radar
Exposure	Source and pathways for encountering hazard	Concurrent weather patterns, topography effects on tornado path
Effects	Types and mechanisms for specific damage to people & property	EF1 tornado, EF5 tornado
Mitigation	Approaches for reducing likelihood, exposure or effects of hazard	Disaster kit, determining safe to leave shelter, safe place
Temporal	Timing impacts on exposure and responses to hazard	Typical times of day, needed warning time
Values	Valuation of risk elements that impact hazard assessment & mitigation/ protective action responses	Near miss, prior warning experience

The current study used the Bostrom et al. (1992) hazard mental model approach to identify tornado knowledge among the public in Northern and Central Alabama and South Central Tennessee, which is a region vulnerable to significant tornadoes (Coleman and Dixon 2014). Data was collected only from undergraduate students and from older community members to allow identification of age differences. This paper focuses on examining the identification, exposure, and mitigation categories of the mental model that can be compared with prior tornado knowledge studies.

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2. METHODOLOGY

2.1 *Participants*

Sixty individuals participated in this study conducted through the University of Alabama in Huntsville. Undergraduate students aged 18-45 were recruited through introductory psychology courses. Community members aged 60-75 were recruited by bulletin board flyers and word-of-mouth. All participants were required to have lived in the Southeastern U.S. for at least four consecutive years to ensure a baseline of tornado knowledge based on residence in the same tornado-vulnerable region. Table 2 lists key demographics that generally describe the participant groups.

Table 2. Participant demographics.

Undergraduates (n=30)	Community Members (n=30)
80% aged 19-25	67% aged 65-75
63% Caucasian	77% Caucasian
23% African American	20% African American
53% homes, 27% dorm,	67% homes,
17% apartment,	27% apartment,
3% mobile home	7% townhome
87% smartphones	20% smartphones
	5 have disability
	(5 motor, 1 hearing)

Descriptions of participant weather knowledge and interest are also important given the study focus on tornado knowledge. Most participants (90% of students and 87% of community members) had checked the weather in the past 24 hours. More community members, however, are habitual in checking the weather forecast daily (93%) compared to the 63% of students who check the forecast daily. On the other hand, more students (70%) subscribe to text alerts about the weather than community members (7%). The most frequent source of general weather information for students was cell phone apps (47%), but the most frequent source of general weather information for community members was TV (73%). For learning about tornadoes and warnings, however, both groups chose mass media as their primary source though the percentage was higher for community members (70%) than students (47%). No participant majored in or was majoring in atmospheric science, but two community members had been storm chasers. To understand if participants were interested in learning more about tornadoes, we asked them to rate their interesting in attending a NWS Storm Spotter course on a 5-point Likert scale where 1 was low and 5 was high. Mean interest was moderately low with 2.87 for students and 2.47 for community members, rating scores that were not significantly different, ($t(58) = 1.14$, $p = .26$).

Actual experience with tornado warnings and tornadoes is another critical descriptor of participant groups. As shown in Fig. 1, all participants had experienced at least one tornado warning and nearly 75% had experienced at least 20. In contrast, actual tornado experience was quite low as shown in Fig. 2 with more than half of participants reporting having been in no more than two. Category distribution among students and community members in both comparisons was similar.

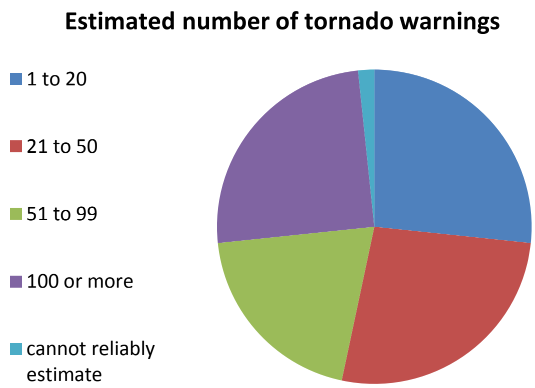

Figure 1. Number of tornado warnings experienced by all participants.

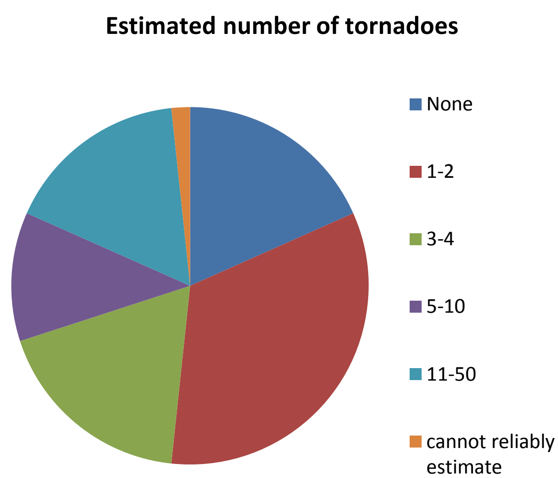

Figure 2. Number of tornadoes experienced by all participants.

2.2 *Procedure*

Interviews were conducted individually by two experimenters. One experimenter guided the questions while the other documented responses on a prepared template. After participants signed a consent form, the interview opened with general probes about tornado knowledge, and the experimenter followed up to obtain elaboration as suggested by the initial responses. Then, the experimenter asked structured questions to ensure participants covered all of the core categories and critical topics. Participants were then given a computer to complete an online questionnaire. All interviews were audio-recorded and professionally transcribed for later analysis. The Institutional Review Board at the University of Alabama in Huntsville approved this study.

The response scoring approach was based on the ISO 9186 (2001) method for assessing the public's comprehension of warning symbols. In this method, each item is individually assessed and graded into one of seven categories as shown in Table 3. Each item was separately coded by two experimenters using answer keys developed in consultation with tornado experts. The experimenters compared scores throughout the process to refine the answer key and to resolve differences for more reliable grading. Point values can also be assigned for each response, allowing quantitative comparisons of scores for different terms, populations, etc.

Table 3. Scoring categories for mental model terms, based on ISO 9186 (2001).

Category	Description	Points given
I	Knowledge certain 80% of complete answer	1.00
II	Knowledge likely 66-79% of complete answer	0.75
III	Knowledge marginally likely 50-65% of complete answer	0.50
IV	Response opposite in meaning to complete, correct answer	-1.00
V	Other responses not categorized (including vague answers)	0.00
VI	Does not know	0.00
VII	No response	0.00

3. RESULTS

3.1 *Identification Knowledge*

During the interviews, participants were asked to explicitly define ten terms typically used during tornado warnings to identify the hazard and explain the potential danger. Table 4 shows the number of participants in each group whose responses were graded into each score category. Given that the best score is category I, this table shows that few participants have certain knowledge of most identification terms. In fact, the scores indicate that participants are *likely* to have correct knowledge (i.e., at least category II) for only four of the terms. This level of knowledge is likely needed before an individual can clearly communicate the correct meaning to another person, so lower knowledge level for many terms suggests that many residents of tornado-vulnerable communities may not be able to prepare newcomers for this hazard. Note, however, that participant knowledge is *marginally likely* to be correct for all but one of the remaining terms, which may allow them to at least recognize the term themselves if given in the right context. The term with the lowest knowledge level was *tornado emergency* for which one-third of all participants provided a category IV (opposite meaning) definition for this term. Most frequently, these participants incorrectly reported that this term is used to describe the tornado aftermath when first responders are needed. Students displayed significantly higher correct knowledge of this term than community members, but only one participant really specified the urgency for dramatic response that this term was intended to convey.

Table 4. Identification term score counts in each ISO 9186 (2001) category[1] by participant group.

Item	Students					Community				
	I	II	III	IV	V & VI	I	II	III	IV	V & VI
Severe thunderstorm warning[2]	6	14	7	0	3	12	14	3	0	1
False alarm[2]	2	16	10	2	0	4	16	7	1	2
Doppler radar[2]	1	13	8	0	8	2	17	8	0	3
Tornado watch[2]	5	16	2	6	1	2	23	1	3	1
Description of tornado	4	14	12	0	0	0	10	16	0	4
Specific information in warning	3	13	9	0	5	1	11	8	3	7
Hook echo	1	1	3	0	25	1	8	11	0	10
Wall cloud	0	1	11	0	18	2	2	10	0	16
Tornado warning	4	6	11	7	2	1	4	18	6	1
Tornado emergency	1	11	7	7	4	0	7	6	13	4

[1] See descriptions of categories in Table 3, with general trend that lower scores are more correct. [2]More than 50% of group participants had scores in Categories I or II.

Although some age differences shown in Table 4 may represent only lower memory recall and elaboration for community members that is typical of older adults, other differences suggest important findings for broadcasters. For example, community members had significantly higher knowledge of *severe thunderstorm warning* and *hook echo* and slightly higher knowledge of *wall cloud* and *Doppler radar* than students. Developing higher knowledge of these terms may be due to closer attention to TV broadcasts by community members who described focusing on the meteorologist's descriptions and images. In contrast, students were more likely to describe receiving initial warnings via their phones and then monitor TV broadcasts while looking at radar apps, the Internet and social media for specific information. Without full attention to the broadcast meteorologist, implicit learning of new terminology and instructions is less likely.

3.2 *Exposure and Mitigation Knowledge*

Ten "tornado myths" previously explored in other research (Hoekstra et al. 2010; Minniear et al. 2011) and authoritative websites (e.g., NOAA/NCDC 2006) were selected to evaluate participant knowledge of how they might be exposed to the tornado and to protect themselves from it. During the interviews each myth was read individually and the participant was asked whether it was true or false. Then, participants were asked to state their confidence in the correctness of their answer on a scale of 0 to 100% because prior research (Alba and Hutchinson 2000) suggests that participant likelihood of using their prior knowledge is correlated with their confidence in the correctness of this knowledge. Participant responses to these questions are shown in Table 5. Note that interviews were concluded with a debrief that provide participants with written explanations of the rationale for debunking each myth to increase confidence in correct knowledge and to reduce confidence in incorrect beliefs.

Table 5. Myth knowledge for Exposure and Mitigation elements of tornado mental model.

	Students			Community Members		
		% Confidence			% Confidence	
Statement and Correct Response	% Correct	Correct	Incorrect	% Correct	Correct	Incorrect
Exposure						
Tornadoes never strike the same place twice (F)	100%	99	--	100%	99	--
Tornadoes don't enter highly populated areas like cities (F)	97%	97	90	97%	96	n/a
Tornadoes can cross water (T)	87%	76	58	93%	90	--
Being on the back of a mountain is safe (F)	70%	70	73	57%	82	71
Tornadoes can survive in mountainous areas (T)	70%	72	73	70%	93	74
Mitigation						
You should open the windows when you hear a tornado warning for your area (F)	93%	93	65	87%	97	86
If you're out driving, you should get out of your car & go lie in a ditch or other low-lying place (T)	87%	93	65	93%	89	85
If you're not at home but out driving, you can take shelter under a highway overpass to stay safe from a tornado (F)	47%	90	80	60%	80	77

Participant knowledge of their vulnerability to tornadoes demonstrated in the Exposure myths is generally high, particularly for the myths about tornadoes in cities and returning to the same location which are contradicted by examples in the surveyed region. More than 30% of participants, however, demonstrated the typical difficulty in reasoning about how mountains affect tornadoes. Although some participants cited examples to reach the correct conclusion, incorrect conclusions were reached when participant reasoning was based on a false belief that essentially says "mountains kill tornadoes" (Klockow et al. 2014). Note, however, that participant confidence in their answers (correct and incorrect) is less than 80%, suggesting that participant beliefs about the role of mountains can be changed.

Table 5 shows that a significant majority of participants have the correct Mitigation knowledge about not opening windows and sheltering in a ditch if necessary, but only about half of participants have the correct understanding about not sheltering under overpasses. Responses to the Mitigation myths also highlight the importance of evaluating participant confidence in their responses to determine whether information provided concurrently with instructions can overcome incorrect knowledge. In the "open the windows" myth, for example, students with incorrect knowledge reported lower confidence in their response. Supporting comments indicated that they thought that the recommendation may have changed but they were not sure, so authoritative instructions would likely be heeded if they were attended. In contrast, the community members with incorrect responses about this myth were confident enough to explicitly recommend opening the windows as part of their warning sheltering practice. Likewise, both students and community members with incorrect responses to the "sheltering under an overpass" scenario were very confident in this action as being safe and protective. In fact, one community member reported having sheltered from a near miss tornado in the past by parking a motorcycle under an overpass. Upon discussing the incident with a friend afterwards, she incorrectly learned that she would have been safer if she had crawled up under the rafters. Thus, she was very surprised to learn from the study debrief that overpasses are very dangerous during tornadoes. If she faced the option during a tornado warning while driving, it seems unlikely she would overcome her prior belief that this was safe even with explicit directions for another protective action.

4. DISCUSSION

4.1 *Summary*

Results of our assessment of tornado knowledge among residents of a tornado-vulnerable region suggest that identification knowledge is only marginally likely to be correct. Thus, warnings and supplementary communication such as protective action recommendations and broadcaster explanations are needed by most people to facilitate full comprehension and correct action selection. Age differences in knowledge suggest different attention to mass media during tornado warnings.

Examining more complex knowledge of tornado exposure and mitigation suggests that most participants have correct knowledge when they have accurate knowledge of concrete examples. Incorrect beliefs were more likely when participants tried to reason about the correct answer, indicated by lower confidence in their responses as well as explanation of their response. Yet, this lower confidence may facilitate knowledge correction or at least adherence to accurate authoritative guidance (Alba and Hutchinson 2000). More problematic is high confidence in incorrect information such as noted for beliefs that sheltering under overpasses is safe, a belief affirmed by nearly 50% of participants in both age groups. This frequency is actually higher than identified in prior research (Hoekstra et al. 2010), perhaps because few individuals have experience or concrete examples to facilitate correction. In contrast, the frequency of affirming the myth that windows should be opened during a warning was lower than Hoekstra et al. found. Because all participants described actually having been at home during tornado warnings, many may have recognized the general prudence of closing windows to keep out the rain and wind that typically accompany stormy weather. Few participants had been in cars during tornado warnings, and several specifically described uncertainty about the best response and desire to not have to make a sheltering decision while in a car. Thus, warning communications that emphasize advance preparations to keep people in the location where they feel most competent may mitigate the danger of incorrect beliefs that may be difficult to correct.

One limitation of these mental model scores is that they are dependent on the answer key that dictates required elements to obtain high scores. For example, earning a category II score for *tornado warning* requires not only that the participant indicate that a tornado has been identified in the warning area but also that they should take shelter. In contrast, earning a category II score for *tornado watch* required only that the participant indicate that tornadoes were possible for the watch area even though better responses also noted that an individual should be alert to changing conditions. Subject matter experts indicated that these definitions were based on current NWS practices. Yet, this discrepancy in definition categorization may suggest a bigger difference than actually affects resident behavior. As described in other research (e.g., Sherman-Morris 2010), some of our participants said that they get the terms confused. Indeed, several provided the meaning for *tornado watch* when asked for the definition of *tornado warning* and vice versa. Yet, participants later used *tornado warning* correctly in describing the recommended response which may be more typical of their implicit understanding of the term in context, such as with instructions to shelter in a short timeframe. The longer timeframes provided with tornado watches may implicitly communicate that this is only a watch with a more passive response suggested.

4.2 *Recommendations for Broadcasters*

Our findings suggest several recommendations that can be implemented in the near term. In general, broadcasters should remember that most viewers are primarily watching for specific guidance about the unique situation facing them in the near future, especially that which is different from the typical or most recent experience that people frequently reference for familiar situations.

- Provide context and elaboration around technical terminology such as *wall cloud* and *tornado emergency* to develop audience understanding. Higher understanding among residents attending to the media may be particularly important for accurate peer-to-peer communication through social media which continues to grow.
- Increase instructions and attention for tornado watches to encourage attention to their planned travel and outdoor activities and need to prepare for communication access in case of escalation to warnings.
- Reiterate specific procedural recommendations for sheltering during warnings, not only for new viewers such as visitors but also for residents who may be in atypical locales.
- Coordinate warning communications across channels to enhance attention to critical details for individuals monitoring multiple sources of information and facilitate sharing accurate recommendations.

4.3 *Next Steps for Researchers*

Findings from this research can be analyzed to answer two important questions typically faced in this research domain. First, our findings about tornado knowledge should be compared with prior research (e.g., Hoekstra et al. 2010, Minniear et al. 2011, Sherman-Morris 2010) to identify best practices for assessing participant knowledge in various situations. Different approaches make further analysis and recommendations difficult, though different needs may dictate tailored approaches for specific situations that can be considered for rapid implementation under the time pressure of post-event surveys. Secondly, analysis of additional data beyond the scope of this paper must be completed and evaluated to develop comprehensive assessments of lay tornado knowledge that encompasses all of the components suggested by Bostrom (2003) and listed in Table 1. From this assessment, identification of key gaps can be identified to direct attention to critical communication needs to promote WRN goals.

In addition, research is needed to evaluate approaches to correcting misinformation about tornadoes such as identified here. As Klockow et al. (2014) highlighted in their descriptions of tornado folk science, misinformation may be particularly difficult to correct when it is incongruent with resident values such as the standard belief that one's home is safe. Psychological research about correcting other knowledge domains such as disease vaccination and climate change based on scientific evidence provides a framework for these investigations (e.g., Lewandowsky et al. 2012), but cooperation with broadcasters and new media companies will be essential to evaluate specific approaches. Thus, effecting weather resilience will require continued collaboration not only between social and physical scientists but also between researchers and practitioners.

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