Tornado Warning Response and Perceptions among Undergraduates in Nebraska

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(Manuscript received 21 March 2016, in final form 5 December 2016)

ABSTRACT

Few studies show how university students perceive and respond to tornado warnings. Lacking in the literature are investigations of what influences perceptions of tornado risk among this population and how these perceptions may influence actions. Through an online survey of 640 undergraduates enrolled at a large university in Nebraska, significant relationships were found between student demographics, perceptions, and response actions. Tornado mythology relevant to the local city influenced perceptions so that students felt the city was less at risk than surrounding rural land. Confirming risk before sheltering remained popular, with some students choosing to never seek shelter during a warning. International students were more likely to initially seek shelter during a warning but had difficulty interpreting warning polygons or accurately choosing the best safety actions. Tornado-related education resulted in international students being more likely to have safety plans and shelter in more appropriate locations. Most domestic students correctly identified safe areas in which to shelter, but fewer knew the precise meaning of a tornado warning polygon. Parents/guardians and the school were the most popular tornado knowledge sources for domestic students, while friends and self-education were popular with international students. Respondents seemed willing to learn more about tornadoes and perceived a lack of tornado-related resources available on campus. This implies that more thorough tornado education and information dissemination on university campuses is warranted. Faster personalization of risk, dispelling local myths, and educating those new to tornado-prone locations should be emphasized.

1. Introduction

In spite of improved detection and warning lead times there are still numerous fatalities and casualties caused by tornadoes. In an attempt to mitigate these by strengthening and maintaining community resilience, the National Oceanic and Atmospheric Administration (NOAA) has created an outreach program with the goal of having a completely Weather-Ready Nation. An integral part of this initiative is the National Weather Service (NWS) StormReady campaign, which involves meteorologists collaborating with local communities, commercial sites, tribal nations, and universities. To be designated StormReady, universities are required to meet certain criteria set by the NWS, such as having hazardous weather plans, having numerous ways to receive and relay warning information to the school’s population, and other criteria. At the time of this writing, there are 204 universities nationwide that have the StormReady distinction (NWS 2017a). With over 22 million students estimated to be on university campuses in 2016 [National Center for Education Statistics (NCES) 2016], it is crucial to keep the number of StormReady campuses growing. Building a more weather-resilient nation does not stop at warning issuance and dissemination through university administration, however. Critical parts of the warning process at the university level include typical response actions and perceptions of students. Since student actions and perceptions have so far been seldom studied, it will be useful to know how they usually obtain, perceive, and ultimately respond to tornado-related information. The goal of this paper is to attempt to answer the following questions:

1) What sources are popular for tornado warnings and tornado-related knowledge among university students?
2) How do students perceive tornado warnings and tornado-related risk? What factors strongly influence these perceptions?
3) How do students respond to warnings and where do they choose to shelter? What factors strongly influence these decisions?
4) What are the perceptions, knowledge, and safety actions of international students?

2. Literature review

a. Warning response process

Milet and Sorensen (1990) summarized the warning response process as hearing and understanding a warning, believing it to be true, and personalizing the risk associated with it before taking action. Instead of passively awaiting updated information, those under a warning tend to actively seek it from additional sources, a behavior found in other studies of tornado warning response (e.g., Chaney and Weaver 2008; NWS 2011). Lindell and Perry (2012) further elaborated on the warning response process with the updated Protective Action Decision Model (PADM). Under the PADM, two important questions people ask when faced with a warning are “do I need to take protective action” and “does protective action need to be taken now?” To assess their own personal risk, people seek out more information about the threat. Information seeking may also arise to cope with any uncertainty in the warning message, perceived or otherwise (Lindell and Perry 2012). For tornado warnings this uncertainty could include which locations are most at risk or one’s location with respect to the tornado. Not comprehending the warning message, a lack of knowing appropriate response actions, and a lack of other people to discuss response options with can all delay sheltering actions. Additional information about a tornado threat may come from environmental cues or social cues, which can influence risk perceptions of the threat, which in turn influence the decision to act (Balluz et al. 2000; Comstock and Mallonee 2005; Lindell and Perry 2012; Silver and Andrey 2014). In surveyed students (Jauernic and Van Den Broeke 2016), 15% reported needing to physically see or hear a tornado before seeking shelter, and 7% took shelter only if others were seen sheltering or if the student was responsible for the well-being of others.

b. Factors influencing warning response

Factors commonly associated with the decision to seek shelter during tornado warnings include being female (Comstock and Mallonee 2005; Nagele and Trainor 2012; Silver and Andrey 2014; Paul et al. 2015; Ripberger et al. 2015) and having a tornado safety plan (Balluz et al. 2000; Nagele and Trainor 2012). The source from which students learn their tornado-related knowledge may also impact warning response. Having parents as this knowledge source may be beneficial, as students reporting this source are more likely to have a safety plan at home and are more likely to respond to a warning in some way (Jauernic and Van Den Broeke 2016). Knowing what knowledge sources are popular among domestic and international students, along with information and perceptions likely communicated through these sources may also be beneficial. Tornado warning sources may also influence response actions and perceptions. Jauernic and Van Den Broeke (2016) found students primarily warned through sirens had a higher likelihood of responding to the warning in some way, although this did not necessarily indicate seeking shelter. In general, if a hazard warning source is perceived as credible and reliable, a person may personalize and heed the warning system more readily (Milet and Sorensen 1990; LeClerc and Joslyn 2015).

Some factors, such as prior experience and perceived false alarm rate (pFAR), have had mixed results for warning response. Some studies find that prior tornado experience, either direct or indirect, can lead to increased use of and more awareness of sheltering plans (Senkeib et al. 2012), a willingness to learn about and prepare for future tornadoes (Blanchard-Boehm and Cook 2004), and even an increase in warning response rate (Silver and Andrey 2014). Other studies have found no effect of prior experience on future behavior (Nagele and Trainor 2012) or even an inverse relationship between prior experience with nonverifying tornado warnings and warning compliance (Paul et al. 2015). There has also been disagreement among researchers concerning the impact of pFAR on future warning response. Some suggest a higher pFAR leads to distrust in a warning system and less tendency to follow future advice and warnings (LeClerc and Joslyn 2015; Ripberger et al. 2015). Other studies suggest false alarms have little or no impact on people’s subjective pFAR and safety responses (Dow and Cutter 1998; Schultz et al. 2010). The study presented herein briefly explores how experience and pFAR influence students’ perceptions of tornado risk and warning response.

c. Tornado risk perceptions

Many people do not perceive tornadoes as particularly threatening events, which gives a false sense of security (Mitchem 2003; Schultz et al. 2010). Cities are generally seen as less likely to be impacted by tornadoes than rural land (Donner et al. 2012; Klockow et al. 2014). In many cities such as Joplin, Missouri, there is a prevalent belief in a protective bubble around the city (NWS 2011). Investigating if students share similar perceptions as the general public and how these perceptions influence actions taken has seldom been researched. Van Den Broeke and Arthurs (2015) found over 50%
(\(n = 287\)) of students believed their local city to be less vulnerable to tornadoes than the surrounding rural land. The most popular given reason for this was the local myth that the city’s slightly lower elevation made it less susceptible, with other reasons including few historical tornadoes, too many tall buildings, or too much heat or friction produced by the city. Lovekamp and McMahon (2011) investigated student perceptions of risk regarding tornadoes and other natural disasters. Many students reported having a strong fear of tornadoes, yet still perceived their personal risk as too low to cause great concern. One student commented (Lovekamp and McMahon 2011, p. 140), “I have been here 3.5 years and nothing’s happened to me since. So, what’s another semester?” Other students simply did not believe “it could happen to them,” indicating personal optimism bias among college students. Sherman-Morris (2010) found that the “most common reason for [students] not seeking shelter [during a warning] was that they did not believe the tornado was a serious threat.” Suls et al. (2013) showed students being similar to the general population in that they feel less at risk compared to their peers, even if there were no differences between them and their peers to suggest less risk. Identifying students’ prevailing perceptions of tornado warnings and tornado-related risk as well as sources of these perceptions would be beneficial.

d. Why study this population?

Undergraduate students on a university campus are a unique population for study. For many students, this may be the first time they are expected to be autonomous, to be responsible for their own safety, and to use their own judgement in dangerous situations. A university population also offers an opportunity to gather information on international students’ perceptions, knowledge, and safety actions. Research specifically on tornado warning response outside the United States is scarce. In China, there are warnings for thunderstorms, heavy rain, and tropical cyclones, which are displayed on the bottom of television screens and verbally through public radio (Wong and Yan 2002). Although these warnings give the type of severe weather expected, other valuable warning components such as time of issuance, duration, and recommended safety action are not given. Many of the 320 survey participants [in Wong and Yan (2002)] had only vague knowledge of what the warnings indicated, and only 31% \((n = 98)\) reported typically responding to any warnings. As summarized by Miletli and Sorensen (1990) knowledge of a hazard and appropriate protective action to said hazard is positively associated with warning response. It is hypothesized that many international students do not know the best safety actions to take during severe weather, given the relative rarity of tornado occurrence outside the United States. A survey conducted in 2012 started to explore relationships between student demographics, tornado knowledge sources, tornado warning sources, and tornado perceptions (Jauernic and Van Den Broeke 2016). The study presented herein further explores these relationships in a new sample of domestic and international students. It also uncovers other factors related to warning response actions and risk perceptions in specific situations. Comparison of this study to relevant results in Jauernic and Van Den Broeke (2016) will provide a basis for warning response actions, tornado risk perception, and persistence of myths in two separate samples of university students.

3. Methods

a. Design and implementation

Dillman et al. (2000) suggested survey questions having randomized multiple choice lists and using open-ended questions sparingly to increase the completion rate. Open-ended questions were still used in cases where priming students for particular responses might have been an issue. Survey questions shown to students are provided in appendix A. Survey questions covered topics such as tornado-related knowledge sources, tornado warning sources, prior experience with tornadoes and tornado warnings, perceived vulnerability of the city, perceived false alarm rate, perceived safety near a tornado-warned supercell, and sheltering decisions made by students. Survey pretesting was conducted on eight people, half of whom were of international origin. Two were professional meteorologists, four were meteorology students, and two were nonmeteorologists. Any confusion found in survey pretesting was clarified before being administered online. The survey was developed and implemented using Qualtrics software, which enabled the survey to be tailored in real time using student responses, reducing the number of non-applicable questions. An e-mail invitation with a direct link to the survey was sent out to a simple random sample of 5000 American and 1665 international undergraduates enrolled at the researchers’ home institution. This sample was one-third of the total undergraduate population and represented 27% of domestic undergraduates and 93% of international undergraduates, respectively [University of Nebraska–Lincoln (UNL) 2015]. Approximately 3 weeks after the initial invitation, a second and final reminder was sent to the same sample of international students. Deliberately contacting international students again
was done to have a large enough sample to make statistical comparisons with domestic students. After ending the chance to participate, 25 surveys were discarded due to participants not answering any questions beyond basic demographics, resulting in a total of 640 analyzed surveys. Some questions were not forced response, thus some questions were not answered by all 640 students.

b. Statistical analysis methods

Emergent categories were used as coding schemes for open-response questions. For statistical analysis, warning sources were classified into larger categories as shown in Table 1. One group included warning sources such as sirens, radio, and NOAA weather radio. Being established for a longer period of time may have allowed for more possible exposure while students were young children. This group could also be considered the category most applicable to people either outside, working, driving, at school, or otherwise not near a television or computer. The Internet and mobile apps were likewise consolidated, since they represented newer warning technology. Television was left as a separate group because of the large size and a unique combination of attention-grabbing images with the voice of a broadcast meteorologist advising seeking shelter. Knowledge sources were also consolidated with formal education and elementary-level safety drills composing one group. Another group included sources for self-education such as independently reading books and watching historical documentaries. Parents and other formal guardians were left as a single group due to size, and a final group was composed of popular culture, friends/peers (of similar ages to students), and other less common miscellaneous sources.

Association among categorical variables was quantified using the chi-squared statistic, with standardized residuals utilized to determine which variables were significantly different than otherwise expected and contributed most to the total statistic (Sharpe 2015). The Wilcoxon–Mann–Whitney (WMW) rank-sum test (Wilks 2011) was used to investigate differences in median pFAR between groups with different home regions, knowledge sources, warning sources, and perceived vulnerability. This nonparametric test indicates whether two samples are likely to come from different population distributions. It was used because results for many questions were non-Gaussian, and some groups being compared were relatively small. Dependent variables that were of particular interest in this study were whether or not students chose relatively safe locations in which to shelter, how safe they perceived themselves to be near a supercell, and whether or not seeking shelter was their initial reaction under a tornado warning. Logistic regression analyses were conducted to determine factors that may be responsible for the most variation in these dependent variables. Factors believed important given the literature review, (e.g., country of origin, gender, length of residence, prior tornado experience, knowledge sources, and warning sources) were used as independent variables in the regressions to determine which were most influential for perceptions and sheltering decisions (appendix B). For statistical comparison, the states of Texas, Oklahoma, Kansas, Nebraska, and Iowa (shaded in Fig. 1) were defined as the plains states due to the relatively high climatological occurrence of strong tornadoes. Domestic students from the plains were hypothesized to have more accurate knowledge of tornadoes and more appropriate safety actions than those from nonplains states.

c. Survey limitations and assumptions

Because of university policy, only one-third of the total undergraduate population (n = 19,979) was included in the sampling frame (n = 66,665), and the final survey response rate was 9.6% (n = 640). This led to only 3% of the total enrolled undergraduate population being represented. Self-selection bias may have resulted in some nonresponse error, where respondents may be more interested in weather than nonrespondents. Thus, generalization of these results may be tenuous for the entire university or other university populations, but the results presented herein could be used as a foundation for future research. Undercoverage error from students not owning personal computers or having Internet access was thought to be mitigated by the availability of campus computers. Measurement error, introduced by participants not interpreting questions in the way
intended, may have introduced bias in the responses to a few questions. This measurement error could have been reduced through additional nonmeteorologists in the pilot study and by the researchers being present in the room to document pilot study respondents’ thought processes while progressing through the survey. Web-based surveys also have inherent uncertainties, such as emails possibly being flagged as spam, never being seen, or images not loading. There was also inherent subjectivity with open-response items being categorized solely by the lead author; however, a time delay was applied between successive categorizations of items discussed in this paper to decrease subjectivity. It was assumed that self-reported events and actions were being remembered and reported accurately and honestly. Language barrier issues were assumed small, given no obvious and consistent patterns in international student responses to indicate misinterpretation.

4. Results and discussion

a. Demographics, prior experience, and safety plans

Out of 640 respondents, 79% \((n = 507)\) were American and 21% \((n = 133)\) were international. In total, 29 countries and 26 states were represented (Fig. 1). As in Silver and Andrey (2014), female students were unintentionally overrepresented at 62% \((n = 399)\) of surveyed students, although they composed about 47% of the university’s undergraduate population at this time (UNL 2015). Among students in Nebraska for less than 1 yr, 59% \((n = 69)\) were international. All international students were asked if they had ever learned about tornadoes, and 41% \((n = 54)\) replied gaining such knowledge.

Students were asked if they had ever been under a tornado warning and 91% \((n = 579)\) stated that they had. Of those reporting never being warned, the majority were international \((78%, n = 39)\). Students were asked if they or anyone close to them had ever been in a confirmed tornado or had their home damaged by one (item 1, appendix A) with a follow-up question (item 2, appendix A) asking how this experience affected actions during subsequent warnings. Of the 272 students who had prior experience, 51% \((n = 139)\) reported sheltering more readily, taking future warnings more seriously, or paying more attention during warnings. This proportion of the sample was not substantially higher than those reporting that the prior experience made no difference \((49%, n = 132)\). This may show a lack of support for prior experience heavily influencing future perceptions and actions (e.g., Nagele and Trainor 2012), or it may be the result of a flawed survey question, since it did not encompass all possible forms of prior experience. The multiple ways in which prior experience may subconsciously manifest in response actions or perceptions in future events are not fully understood and could be a subject of future research.

Students were asked if they had a safe place to shelter in case of a tornado and knew how to get there (item 3,
appendix A). Not every location (home, school, or work) was applicable to every student. A student’s home or current residence was the most common location for which they had a plan (88%, n = 519), followed by school (78%, n = 549) and work (76%, n = 315). Certain student attributes affected the existence of safety plans. International students (12.2% less likely, χ² = 13.4; p < 0.001) and nonplains students (10% less likely, χ² = 9.1; p = 0.003) were statistically less likely to have safety plans in place at home. This implies students from regions where tornadoes are less prevalent may not know what a safety plan should be or may simply not think about it. International students who were taught about tornadoes before or shortly after arriving to the United States were 17.4% more likely to have safety plans at school than those who were not taught (χ² = 6.3; p = 0.012). This shows value in educating those less familiar with tornado risks. Finally, students gaining tornado-related knowledge from their parents were 9.3% more likely to have a safety plan at home compared to those gaining their knowledge elsewhere (χ² = 7.8; p = 0.005), similar to Jauernic and Van Den Broeke (2016). It would be interesting to see exactly what students are learning from their parents and whether this is simply safety actions or perceptions of tornado behavior.

b. Knowledge and warning sources

Knowledge sources were recorded for all domestic students and any international students who reported having tornado-related education. Students were asked to select their one primary knowledge source from a list of commonly used sources found in Jauernic and Van Den Broeke (2016) (item 4, appendix A). This was followed up by selecting any other secondary sources (item 5, appendix A). The most popular primary knowledge source for domestic students was parents/guardians (20% of respondents, n = 102), followed by elementary school drills (16%, n = 79; Fig. 2). International students were likely to learn about tornadoes from high school classes (21%, n = 10) or their friends and peers (19%, n = 9). Self-education was also popular among international students, showing a willingness to learn more. The most popular secondary knowledge source for all students was local news (63%, n = 350), illustrating the importance in understanding how students interpret television-based information.

Primary and secondary tornado warning sources were similarly reported (items 6 and 7, appendix A). As shown with the general U.S. population (Legates and Biddle 1999; Balluz et al. 2000; Brown et al. 2002; Hammer and Schmidlin 2002; Paul et al. 2003; Comstock and Mallonee 2005; Chaney and Weaver 2008), sirens (30%, n = 145) and television (28%, n = 136) were the most popular among domestic students (Fig. 2). For international students, campus alert (through text message or e-mail) was the most popular at 34% (n = 30). This shows a considerable amount of international students voluntarily signing up for the emergency communication system. It could also indicate international students are not as aware of typical local warning sources and reinforces the need for this segment of the university population to be provided with more warning procedure information. Weather applications (apps) on mobile devices was the third most popular primary warning source for both groups (domestic 18%, n = 85; international 16%, n = 14). This shows an increase in mobile app usage since the fall of 2012 (Jauernic and Van Den Broeke 2016) where only 6% of all students reported newer warning sources such as the Internet, mobile apps, and texts as their primary warning source. Students reporting either primary or secondary warning sources to be television, Internet, text message, or weather apps were asked what specific source they were referencing (Table 2). Local television news (89%, n = 366), The Weather Channel’s website (57%, n = 158),
NWS-based text messages (69%, \( n = 145 \)), and The Weather Channel’s mobile app (68%, \( n = 225 \)) were the most popular in their respective groups.

c. Perceptions of tornado risk

Students judged the tornado vulnerability of the local city compared to a rural area of equal size (item 8, appendix A). They could next select why they believed the city to be more, less, or equally vulnerable (item 9, appendix A). Many students (64%, \( n = 370 \)) correctly believed the local city to be equally vulnerable. However, over one-third (\( n = 198 \)) incorrectly believed the local city was less vulnerable than its surroundings, even if many of them believed cities in general could be impacted (not shown) by tornadoes. This shows the power of local myths and optimism bias. The belief that cities are not affected by tornadoes has been seen in prior work for both university students (Van Den Broeke and Arthurs 2015) and the general population (Donner et al. 2012; Klockow et al. 2014). Some students may have gained incorrect perceptions from their classmates and friends. This is shown by a quote from a student who had prior experience with a tornado, then moved from a rural area to the local city:

“It made me take them a lot [more] seriously when I lived out in the country, as the back half of our property took a lot of damage. However, living in [the local city], I always hear that tornadoes “never hit the city,” so I’ve begun to take it a lot less seriously.

This student is a clear example of having a correct perception of risk changed to complacency because of learning local myths from others. Other studies (Klockow et al. 2014; Paul et al. 2015) have shown local mythology playing a significant role in shaping the perceptions of tornadoes and tornado risk. Risk perception and the percentage of warnings heeded in urban versus rural settings would be useful to investigate further.

A longer residence time in a region susceptible to severe thunderstorms may lead to a greater need to seek out additional information before sheltering. Longer residence time may also result in an assumption that one’s abilities to interpret signs of weather hazards are adequate enough to determine whether sheltering during tornado warnings is necessary. The following insightful comments are from students having prior tornado-related experience but report that the experience did not significantly alter their warning response behavior:

If it is going to hit us I will take shelter, otherwise I will go outside and watch for it until I know for a fact that it will hit my place.

It [prior experience] really hasn’t [changed how I act now]. I grew up in Nebraska, so I can tell when a tornado is actually coming, and when it’s just a warning that my area might be hit.

These responses show a tendency to use personal knowledge to decide when there might genuinely be danger and show a high need for personalization of risk. How do such students know for sure that they will or will not be impacted by a tornado in any given warning situation? The level of confidence in their own self-assessment of personal risk underscores the need for greater understanding of how this population understands and interprets weather threats. Because of familiarity these students may know what safety actions they should take but may not ultimately take them. They may need much stronger environmental and social cues before seeking shelter.

d. Perceptions of false alarms and campus warning messages

Respondents were asked to give the percentage of tornado warnings that they felt resulted in false alarms. Figure 3 shows the average student pFAR for 581 students was highly variable with an average of 45% and a standard deviation of 27%. This is well below the national objective average false alarm rate of 73% and was similar to values found by Ripberger et al. (2015). A WMW analysis shows higher pFARs were associated with a belief that the local city was not equally vulnerable to tornadoes as surrounding rural land (\( p = 0.035 \)).
A higher overall pFAR was hypothesized to be associated with a lower likelihood of seeking shelter as a first action during a warning, as investigated in a later section of this paper.

One variable that may impact student pFAR, but was not directly investigated in this study, is warning message content on campus intercom systems. For this particular campus, warning messages are played during the routine monthly siren test and during real warnings. However, the test warning messages do not contain the word test and are presented as though they are real. A quote from one student shows confusion because of this:

Since I have been living in campus dorms for 4 years, it is hard to notice which is [a] practice alarm and which is the real one for tornadoes.

This type of message could also conceivably increase the pFAR in students' minds, leading to habituation, additional time confirming the risk, and a cavalier attitude in future warning events, especially in those who do not know the monthly testing schedule. This monthly testing schedule also occurs at different times for different cities and states, resulting in additional confusion. In addition to typical tornado warning procedures on campus, and appropriate sheltering locations, students new to the region should be given information regarding monthly testing schedules.

Being designated as StormReady, this campus has signs in many buildings that inform students of appropriate shelter locations. During tornado warnings, emergency alerts are sent out to students through text and e-mail. These alerts require voluntary registration; thus, not all students on campus receive them. The following quotes suggest some students do not know these alerts exist and/or pay no attention to posted signs:

Send more alerts with specific information of what we should know about and do.

More awareness around campus would be nice—like tornado shelters inside the buildings. I can see there being mass chaos due to not knowing shelter areas.

I don’t know much about where to go besides the stairway. I also don’t know…plans in any given building…If [a warning] happened I’d have to rely on people telling me what to do and where to go.

Investigating methods to get more students to sign up for the emergency alerts would be beneficial. These alerts could also be improved by providing more specific information, as they currently state: “The National Weather Service has issued a tornado warning. Move to designated tornado shelters, lower area inside buildings, and away from windows. Follow tornado warning procedures and remain in shelter until the warning expires” (Emergency Alert 2016, personal communication). Tornado warning procedures are vague and could vary between buildings on campus and time of day. Unless students take the time to open, read, and understand the embedded link to the NWS warning product text, they may be lacking critical initial information. This would include the warning expiration time, specific safety procedures for different situations, hazards other than the tornado, impacts to life and property, locations included in the warning, and anticipated motion of the storm.

e. Perceptions of warning polygons, radar imagery, and safety

A tornado warning (indicated by the red polygon) overlaid on a radar reflectivity image of a supercell was shown to students, as in Fig. 4. The accompanying caption shown to students read: “Shown is a picture of a strong storm. The white arrow shows direction of motion, and the yellow star is your location.” Students were asked, “What does the red rectangle mean?” The goal of this question was to obtain students’ gut reaction and interpretation of the tornado warning polygon. The NWS issues tornado warnings when meteorologists on duty believe a tornado to be imminent (NWS 2017b). This occurs when a tornado is indicated by radar or sighted by spotters; therefore, people in the affected area should seek safe shelter immediately (NWS 2017c). Open-response interpretation for the meaning of the red rectangle was given by 543 students. The largest group of students (41%, $n = 222$) had generic responses such as danger zone, high-impact area, or the width of the storm path. This group knew the polygon indicated some type of severe weather that would be cause for concern but did not mention the word tornado in their explanation.
The second most popular response (25%, \( n = 134 \)) was composed of ideas similar to path of the tornado, or area that may be affected by a tornado, but did not mention the word warning. Slightly less than 17% (\( n = 91 \)) specifically said tornado warning. Finally, about 17% (\( n = 96 \)) of students either explicitly stated they did not know or gave answers such as “the region the storm is staying in” or even “it might be the safe area, safe distance from the tornado. I’m not sure.” These responses seemed to indicate a dichotomous perception of safety at the threshold of the polygon, akin to what was found by Ash et al. (2014), representing danger inside the polygon but safety outside. This perception does not take into consideration storm movement or separate warning polygons being issued for new locations as the storm moves and evolves. The wide range of interpretations illustrated here show the need for further education on radar images and the appearance of tornado-warned areas from visual sources. The range of interpretations also underscores the need for clarity in how warning messages are portrayed by different warning sources. Conclusions drawn from these open-response interpretations should be used with caution, however, since this question is limited in its application to real-life warning events. People usually receive these messages with additional information attached, such as the fact that the storm is tornado-warned or specific locations are impacted. This information would be helpful in the process of making a decision on how to respond.

To assess perceived risk associated with the warning polygon and radar imagery, students were shown a five-point scale ranging from complete danger to complete safety and were instructed to choose how safe they would feel if located at the yellow star in Fig. 4. This image was meant to simulate one that some students may have previously been exposed to through Internet, television, or mobile applications. Elements such as locations of towns or spatial scales may not have benefited those unfamiliar with the area and should not have been necessary if students understood the radar image; 81% (\( n = 448 \)) of those who answered the question reported feeling some degree of danger, and 19% (\( n = 106 \)) felt either safe or neutral. By not having a strong opinion, those who felt neutral may put themselves at risk and were thus assigned to the same category as those who felt some degree of safety. International students (\( \chi^2 = 10.3; p = 0.006 \)) and those from nonplains states (\( \chi^2 = 7.6; p = 0.025 \)) were less likely than expected to perceive themselves as safe, while those residing in Nebraska for 5 yr or more were more likely to view themselves as safe (\( \chi^2 = 19.1; p < 0.001 \)). This suggests the more time one has spent in tornado-prone regions, the more accustomed they grow to severe weather and will possibly develop complacency during warnings, as shown by Paul et al. (2015).

Given the limitations of having a radar image with no informative text, future work could further explore the relationship between residence time and perceived safety in a variety of severe storm situations. It cannot be determined whether the radar image or the warning polygon was more influential on perceived safety and may depend on the context in which students receive warning messages.

A regression analysis was used to explain variability in perceived safety near the supercell with respect to many factors. It was found that polygon interpretation may have been responsible for some variance in perceived safety that was not explained by student demographics or knowledge sources. Students who did not associate the word tornado with the warning polygon were nearly twice as likely to report feeling some degree of safety near the supercell (see Table B1; \( p = 0.018 \)). This shows incorrect knowledge leading to incorrect perceptions of risk. This is similar to Jauernic and Van Den Broeke (2016), where students who could not correctly define a tornado warning in an open-response question were significantly less likely to have immediately taken shelter during the last warning they experienced. Overall, the nearly 20% of students reporting feeling some degree of safety suggests more severe storm education is warranted for both long-term residents of tornado-prone areas and those new to these areas. However, these results may vary depending on what information accompanies the warning. A different proportion of students may have felt safe if they were provided with the fact that they were looking at a tornado-warned storm.
f. Intended sheltering locations

When asked to supply a location that would be safe during a tornado (open response), many students generically said the basement. International students were significantly less likely to supply a specific shelter location, instead offering generic answers such as indoors, school, dorm or apartment, or explicitly state that they did not know where to go ($\chi^2 = 46.8; p < 0.001$). Responses fell within a spectrum of degree of safety, and some responses may not have been able to be categorized as strictly safe or unsafe. Some reported less-safe options such as the lower central hallway or stairwell of an apartment complex, which may be the best option available to them. In addition to this open-response question, students were shown a floor plan of a basement (Fig. 5) and were asked “where would be the safest place during a tornado?” They were instructed to select between one and three locations. Safe locations were defined as small, windowless, interior rooms (NWS 2017d), away from the building perimeter. Locations not matching these criteria were classified as relatively unsafe. It was made clear in the question text that north was located at the top of the page and that the image represented a plan view looking down from above. Responses show the interior bathroom and the space underneath the stairs were the most popular choices, as both options had just over 57% of students choosing them. The southwest corner was the most popular corner, demonstrating persistence of the antiquated myth that it is safest (Tornado Project Online 2015). A logistic regression analysis was used to explain possible variability in sheltering choices (see Table B2). It was found that home origin and gender accounted for some variance not explained by other factors such as residence length, prior experience, or knowledge sources. International students were 2.6 times more likely to choose relatively unsafe locations (Fig. 6; $p = 0.024$), and female students were 1.6 times more likely to choose such a location (not shown; $p = 0.017$). A separate regression analysis solely for international students (see Table B3) shows those not taught any tornado-related information before or shortly after arriving in the United States were 4.4 times more likely to choose an unsafe location (Fig. 7; $p = 0.006$) than those who were taught. This reiterates the value of severe weather education for those new to tornado-prone areas. It was assumed students would realize windows were present on all four sides of the hypothetical basement, but there may have been difficulty interpreting the image as intended. Thus, generalizing these results should be done with caution.

g. Response actions and factors influencing sheltering during warnings

Students selected their typical first action taken during any tornado warning from a list of popular actions given in an open-response item in Jauernic and Van Den
These included taking shelter, going outside to watch the storm, watching news, watching radar, or ignoring the warning. The most popular response was confirming the warning by numerous means, with 61% ($n = 332$) of students choosing this type of response, supporting studies of the general population and of students (e.g., Sherman-Morris 2010). Specific actions taken to confirm the threat, as well as the percentage of students who would shelter or ignore the warning, are shown in Table 3. Since all warnings are spatially and temporally different, and students may perform a sequence of different actions during a single warning, they were next asked during what percentage of tornado warnings they ultimately chose to take shelter. As shown in Fig. 8, the average shelter rate for 556 students was 51% with a standard deviation of 33%. A clear bimodal distribution is shown, which could indicate a tendency for students to develop habits of usually responding to warnings or seldom responding to any warnings, with little middle ground. Nearly 40% ($n = 218$) of students ultimately chose to never seek shelter during two-thirds of all warnings they experience, possibly leaving themselves vulnerable for the majority of warnings.

Using logistic regression, it was found that home origin, gender, warning source, and pFAR were responsible for some variance in initial response actions (see Table B4). International students were 5.5 times more likely to initially seek shelter than American students ($p < 0.001$), though this does not imply they were choosing correct places to shelter, as discussed earlier. Domestic students, having experienced severe thunderstorms or tornadoes more often, may develop a stronger need to confirm the warning rather than initially taking shelter. International students who reported being taught tornado-related information were 7 times more likely to initially shelter (see Table B5; $p = 0.001$) than those who were not taught. Females were twice as likely to initially shelter as males ($p = 0.004$), reiterating the consensus in the literature. Students receiving warnings through more readily established auditory sources (e.g., sirens, radio, or NOAA weather radio) were 2.3 times more likely to initially shelter than those primarily receiving warnings through newer technology (e.g., Internet or mobile technology; $p = 0.003$). This may indicate newer warning technology such as mobile weather apps might be used primarily for confirmation. Alternatively, these sources may also offer more geospatially specific information. If students perceive less danger from the newer warning sources, then they may be less likely to initially seek shelter. Finally, for every 1% increase in pFAR, the odds of students initially sheltering decreased by nearly 1% ($p = 0.042$). As students believe more warnings are simply false alarms, their odds of seeking shelter slightly decrease. Instead, they may feel more of a need to confirm the warning first before taking any other actions. This reiterates findings from LeClerc and Joslyn (2015) in which a higher pFAR was associated with lowered trust in warnings.

### 5. Summary and conclusions

The warning response process is complex and influenced by many dynamic factors. This study explored this process for tornado warnings, with an emphasis on how

<table>
<thead>
<tr>
<th>Specific action</th>
<th>Action usually initially taken during a tornado warning.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to basement</td>
<td>30% ($n = 167$)</td>
</tr>
<tr>
<td>Go outside</td>
<td>22% ($n = 120$)</td>
</tr>
<tr>
<td>Watch news</td>
<td>15% ($n = 85$)</td>
</tr>
<tr>
<td>Watch radar</td>
<td>10% ($n = 58$)</td>
</tr>
<tr>
<td>Ignore</td>
<td>8% ($n = 43$)</td>
</tr>
<tr>
<td>Watch from window</td>
<td>7% ($n = 38$)</td>
</tr>
<tr>
<td>Listen to radio</td>
<td>5% ($n = 27$)</td>
</tr>
<tr>
<td>Other*</td>
<td>3% ($n = 18$)</td>
</tr>
</tbody>
</table>

*Watch nonnews TV, chase storm
it may be modified by demographics, risk perception, knowledge sources, and warning sources of university students. Popular tornado-related knowledge sources for domestic students were parents and elementary-level classes and practice drills. For international students, popular sources included high school, friends, and self-education. Although not as popular as sirens or television, newer technology such as mobile weather apps and the Internet seem to be gaining popularity as warning sources. The majority of plains students had safety plans, although this was less likely to be true for international students and domestic students from nonplains regions. Prior experience with tornadoes did not significantly change some students’ perceptions or response in future warning situations, although the measure of prior experience in this study could have been improved.

Students on average perceived a lower subjective false alarm rate than the national objective average; however, there was much variability in perceived false alarm rate, and some students believed all warnings resulted in a false alarm. An increase in perceived false alarm rate was also associated with a lower likelihood of initially seeking shelter. When asked how often they ultimately take shelter during warnings, some students reported never seeking shelter. These types of students may instead require a much more persuasive cue to motivate sheltering, such as seeing or hearing a tornado. Many believed the local city was less vulnerable to tornadoes than its surroundings because of its slightly lower elevation. Those not originally from the city could easily hear this myth from their peers. This may especially affect international students, given the popularity of friends and peers as preferred knowledge sources. International students had difficulty interpreting warning polygons or accurately choosing the safest location during a tornado. However, they exhibited willingness to learn more about severe weather, and many voluntarily signed up for the campus emergency alert system. Tornado-related education seems to positively impact international students, as those who had such education were more likely to have safety plans and shelter in more appropriate locations. Overall, international students sheltered more readily than domestic students, perhaps because they had not developed the skepticism of longer-term residents who have a higher need to confirm a warning before taking any protective action.

Many students in this study perceived tornado safety knowledge to be lacking on campus. They desired more specific information regarding safety actions and where exactly to go while on campus. The warning messages disseminated to them through the university could contain more specific information such as the duration and expiration time of warnings and clarify the tornado warning procedures that should be taken. For universities located in areas where tornadoes often occur, more information could be distributed on campuses regarding monthly testing schedules to reduce the impact of perceived false alarms. Future work could investigate the content of emergency alert systems on other campuses and could determine tornado mythology popular in other tornado-prone cities with large universities or with large international resident populations. Exploring the level of trust in popular warning sources as well as its influence on warning response actions would also be beneficial.

Many institutions are becoming StormReady, but individual students vary in their preparedness. Differing perceptions of risk were found between students originally from tornado-prone regions and students outside these regions. Thus, motivating those in warning situations to quickly seek shelter may require two different approaches. For those new to tornado-prone areas, receiving more information on tornado warning procedures, local testing schedules, and appropriate sheltering locations may be the most beneficial. Alternatively, those from tornado-prone states can grow overly confident in their abilities to accurately assess when to seek shelter, or they may grow complacent during warnings. The most effective method of motivating this group with more familiarity to quickly seek shelter remains to be investigated.

Acknowledgments. The lead author was supported by a teaching assistantship and the second author was supported by an academic appointment at the University of Nebraska–Lincoln. We thank the three reviewers who greatly improved the manuscript with their helpful comments. The students who participated in the survey are very much appreciated.
APPENDIX A

Questions and Coding Rubrics

1) Have you or anyone close to you (family or friends) ever been in a tornado or had part of their home damaged by a confirmed tornado?

2) (Follow-up to 1) How (if at all) has this experience affected how you act during warnings following this?

3) Do you have a safety plan you could use immediately in case of a tornado? Meaning do you have a safe place to go and know how to get there?
   - At home (current residence)? Yes No Does not apply
   - At work? Yes No Does not apply
   - At school? Yes No Does not apply

4) What is the 1 major (primary) source from which you learned the most about tornadoes and tornado safety?
   - Elementary school safety drills
   - Elementary school classes
   - High school science classes
   - College earth and atmospheric science courses
   - Parents/guardians
   - Friends/colleagues/coworkers
   - Local T.V. News station
   - Self-educated (reading books/online sources)
   - Personal experience of severe weather
   - Popular culture (Twister, storm chasing shows)
   - Documentary/National Geographic/Science channel
   - Other source ____________
   - I have not learned about tornadoes, my home country or state does not have them.

5) (Follow-up to 4) Are there any other sources that you have learned about tornadoes from? (Students were shown the same knowledge source list with their selected primary source removed.)

TABLE B1. Regression parameters for variables influencing chosen sheltering location (between relatively safe and unsafe) for all students. Significant variables are in bold font.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta estimate</th>
<th>Odds ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>-0.96</td>
<td>0.39</td>
<td>0.024</td>
</tr>
<tr>
<td>Gender</td>
<td>0.49</td>
<td>1.63</td>
<td>0.017</td>
</tr>
<tr>
<td>Residence</td>
<td>0.24</td>
<td>1.27</td>
<td>0.139</td>
</tr>
<tr>
<td>Experience</td>
<td>0.10</td>
<td>1.11</td>
<td>0.619</td>
</tr>
<tr>
<td>Knowledge source 1</td>
<td>0.08</td>
<td>1.08</td>
<td>0.782</td>
</tr>
<tr>
<td>Knowledge source 2</td>
<td>-0.01</td>
<td>0.99</td>
<td>0.963</td>
</tr>
<tr>
<td>Knowledge source 3</td>
<td>-0.03</td>
<td>0.97</td>
<td>0.936</td>
</tr>
</tbody>
</table>

* Length of residence in Nebraska.
* Parents (reference group: formal education and safety drills).
* Self-education.
* Friends, peers, common knowledge, and popular culture.

TABLE B2. As in Table B1, but for regression parameters for variables influencing chosen sheltering location solely for international students. Significant variables are in bold font.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta estimate</th>
<th>Odds ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.73</td>
<td>2.08</td>
<td>0.161</td>
</tr>
<tr>
<td>Residence</td>
<td>0.63</td>
<td>1.88</td>
<td>0.164</td>
</tr>
<tr>
<td>Taught*</td>
<td>-1.47</td>
<td>0.23</td>
<td>0.006</td>
</tr>
</tbody>
</table>

* Whether or not international students were taught about tornadoes.

6) What is your 1 major (primary) source for tornado warnings?
   - Weather radio
   - Public radio
   - Speaking face to face with others
   - Building intercoms
   - Sirens
   - T.V.
     - Local news
     - The Weather Channel
     - Weather Nation
     - Other_____
   - Phone call from another person
   - Text message
     - From parent or family
     - From peer (someone your age)
     - From National Weather Service
     - Other_____
   - Mobile campus alert
     - E-mail
     - Text notification
     - Other_____
   - Weather app on mobile device
     - Weather Channel app
     - Weather Bug
     - Radar Scope
     - Other app ________

TABLE B3. As in Table B1, but for regression parameters for variables influencing perceived safety near supercell. Significant variables are in bold font.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta estimate</th>
<th>Odds ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>0.38</td>
<td>1.46</td>
<td>0.461</td>
</tr>
<tr>
<td>Gender</td>
<td>0.48</td>
<td>1.62</td>
<td>0.066</td>
</tr>
<tr>
<td>Residence</td>
<td>0.22</td>
<td>1.25</td>
<td>0.327</td>
</tr>
<tr>
<td>Experience</td>
<td>0.06</td>
<td>1.06</td>
<td>0.826</td>
</tr>
<tr>
<td>Knowledge source 2</td>
<td>0.18</td>
<td>1.20</td>
<td>0.606</td>
</tr>
<tr>
<td>Knowledge source 3</td>
<td>0.22</td>
<td>1.25</td>
<td>0.466</td>
</tr>
<tr>
<td>Knowledge source 4</td>
<td>0.44</td>
<td>1.55</td>
<td>0.359</td>
</tr>
<tr>
<td>Polygon*</td>
<td>-0.63</td>
<td>0.53</td>
<td>0.018</td>
</tr>
</tbody>
</table>

* Interpretation of tornado warning polygon (open written response).
TABLE B4. Regression parameters for variables influencing decision to initially shelter for all students. Significant variables are in bold font.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta estimate</th>
<th>Odds ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>-1.69</td>
<td>0.18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender</td>
<td>0.69</td>
<td>1.99</td>
<td>0.004</td>
</tr>
<tr>
<td>Residence</td>
<td>-0.08</td>
<td>0.92</td>
<td>0.653</td>
</tr>
<tr>
<td>Experience</td>
<td>0.12</td>
<td>1.12</td>
<td>0.619</td>
</tr>
<tr>
<td>Warning source 2</td>
<td>-0.40</td>
<td>0.67</td>
<td>0.136</td>
</tr>
<tr>
<td>Warning source 3</td>
<td>-0.83</td>
<td>0.44</td>
<td>0.003</td>
</tr>
<tr>
<td>pFAR</td>
<td>-0.01</td>
<td>0.99</td>
<td>0.042</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>-0.21</td>
<td>0.81</td>
<td>0.370</td>
</tr>
</tbody>
</table>

a Television (reference group: auditory/traditional sources).
b Newer technology (weather applications and text messages).
c Perceived tornado warning false alarm rate.
d Perceived vulnerability of local city.

TABLE B5. As in Table B4, but for regression parameters for variables influencing decision to initially shelter for international students only. Significant variables are in bold font.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta estimate</th>
<th>Odds ratio</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.89</td>
<td>2.44</td>
<td>0.146</td>
</tr>
<tr>
<td>Residence</td>
<td>-0.57</td>
<td>0.57</td>
<td>0.268</td>
</tr>
<tr>
<td>Experience</td>
<td>-2.41</td>
<td>0.09</td>
<td>0.045</td>
</tr>
<tr>
<td>Warning source 2</td>
<td>-1.07</td>
<td>0.34</td>
<td>0.465</td>
</tr>
<tr>
<td>Warning source 3</td>
<td>-0.22</td>
<td>0.80</td>
<td>0.722</td>
</tr>
<tr>
<td>pFAR</td>
<td>0.00</td>
<td>1.00</td>
<td>0.984</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>-0.14</td>
<td>0.87</td>
<td>0.831</td>
</tr>
<tr>
<td>Taught</td>
<td>1.97</td>
<td>7.17</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The number of international students with experience was deemed too small to be meaningful.
Whether or not international students were taught about tornadoes.

APPENDIX B

Tables containing independent variables used in regression analysis to determine which variables were most influential for perceptions and sheltering decisions (Tables B1–B5).

REFERENCES


