Tornado Warnings at Night: Who Gets the Message?

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ABSTRACT

Nocturnal tornadoes are a public health threat, over twice as likely to have fatalities as tornadoes during the day. While tornado warning receipt is an important factor in models of individual behavioral response, receipt of warnings at night has not been studied in the literature to date. This study uses survey data from a random sample of Tennessee residents ($N = 1804$) who were randomly assigned to day or night versions of a near-identical survey instrument. Bivariate and logistic regression analyses compare chance of warning receipt, warning sources, and predictors of warning receipt for day versus night scenarios of a tornadic event. Over 80% of participants asked about a daytime tornado said there was a high/very high chance of receiving the warning, compared to fewer than 50% of participants asked about a nighttime event. Whereas demographic and cognitive factors helped predict tornado warning receipt during the day, cognitive and geographic factors were salient for the night. Perceived county risk and prior experience with a tornado were positively associated with chance of nighttime receipt, while belief that luck is an important factor in surviving a tornado and living in east (compared to west) Tennessee were negatively associated. Future research should consider partnering with the National Weather Service, emergency managers, and local media to increase the likelihood that people will receive tornado warnings at night and to better understand the role that cognitive factors and particular beliefs play in individual efforts to ensure that warnings are received.

1. Introduction

Nocturnal tornadoes are a public health threat. While less frequent than daytime tornadoes, they are 2.5 times as likely to kill (Ashley et al. 2008) and more likely to cause injuries (Simmons and Sutter 2009). From 1950 to 2005, 2% of daytime tornadoes were fatal, compared to 3.9% of nocturnal ones, a statistically significant difference indicating a much higher relative risk to the public at night (Ashley et al. 2008). In the southeastern United States, a relatively high proportion of tornadoes occur at night. In Tennessee, the setting for this study, an estimated 45.8% of tornadoes from 1950 to 2005 were nocturnal, and 61.4% of those were killer events (Ashley et al. 2008).

Models of protective action in response to environmental hazards such as tornadoes include warning messages, information sources, and environmental and social cues as influential factors in a person's behavioral response (Lindell and Perry 2012). In Brotzge and Donner's (2013) summary of individual factors leading to behavioral response, warning receipt is an essential first step in a sequence of events related to protective action. At night, however, people may be less likely to receive warnings or other information if they are asleep (Simmons and Sutter 2005). If woken by a warning, they

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may be less likely to receive environmental cues (e.g., unable to see the weather themselves) or social cues (e.g., not in contact with people who might encourage protective action).

In addition, there are forecasting challenges unique to nocturnal tornadoes that must be considered (Kis and Straka 2010) and that may impact warning communications, false alarm rates, and public attention to warnings at night (Simmons and Sutter 2009). Prior research suggests that the nocturnal tornado environment is different from that during the day; in fact, the environment that is unfavorable for daytime tornadoes may be favorable for nocturnal ones (Kis and Straka 2010). Also, nocturnal tornadoes are more likely to go unwarned than tornadoes during the day (Brotzge and Erickson 2010).

Prior studies of tornado warning receipt and related information seeking (in general or during the day) have found associations with demographic characteristics and household resources. Women have been found more likely than men to seek severe weather information (Silver 2015). People ages 50 and older seem more likely to receive weather information from television (Durage et al. 2014) and to trust the National Weather Service (NWS) (Ripberger et al. 2015) than their younger counterparts. Cell phone access has been associated with tornado warning receipt and may be a preferred way of receiving weather information for younger adults (Burke et al. 2012; Durage et al. 2014). Meanwhile, both lower ($\$35\,000\,\mathrm{yr}^{-1}$ or less) and higher ($\$100\,000\,\mathrm{yr}^{-1}$ or more) household incomes have been associated with increased likelihood of receiving severe weather information via smartphone applications (Silver 2015).

Despite this growing research on who receives tornado warnings or related information and how this information is received, no studies have examined these aspects explicitly for nocturnal tornadoes, despite the fatality risk that nocturnal events pose to the public. While Simmons and Sutter (2005), for example, posit that higher nighttime fatalities may be due to lack of warning receipt, they note that empirical data supporting this assertion is lacking.

Motivated by a goal of reducing tornado fatalities at night, this study examines who receives nocturnal tornado warnings and how this differs from warnings during the day. Using a randomized survey design, we compare chance of warning receipt, warning sources, and predictors of warning receipt for daytime versus nighttime tornado scenarios among residents of three regions in Tennessee—a state with a relatively higher risk of nocturnal tornado fatality (Ashley et al. 2008), but where tornado incidence varies geographically across the state (Brown et al. 2016).

2. Methods

a. Sampling and data collection

Data are from randomly sampled phone surveys ($N = 1804$) administered to residents of 12 Tennessee counties from February to July 2016. We included four counties from each Tennessee region (west, middle, and east): the counties that include the major cities of Memphis, Nashville, and Knoxville, and three nearby counties for each of these cities (Fig. 1). Based on 2014 U.S. census data, we selected counties for their range of socioeconomic characteristics.

Prospective participants were recruited by phone using a randomly sampled list of landline and cell phone numbers in included counties. Response rates were 14.1% and 19.7% for the landline and cell phone samples, respectively. The survey was administered with computer-assisted telephone interviewing technology. Participants provided verbal informed consent and received a $10 gift card for their time.

To investigate differences related to tornadoes that occur during the day versus at night, we created two near-identical versions of the survey. The versions differed only in wording for select items about whether the question pertained to daytime or nighttime tornadoes or tornado warnings. Participants were randomly assigned to either survey version. Our target sample size ($N = 1800$; 900 for each survey version) was set with expectation of sufficient power to detect an effect size of 0.10 with $\alpha = 0.05$ and $\beta = 0.80$ (Ellis 2010).

b. Measures

1) Dependent variables

We measured likelihood of receiving a tornado warning with the question, "If there was a tornado warning during the [daytime/nighttime when most people are asleep], what are the chances you would find out about the warning?" Participants chose from no chance, very low, low, high, and very high. For regression analysis, based on distribution of the data and for consistency between day and night analyses, we created a dichotomous measure (0 = no/very low/low chance, 1 = high/very high chance).

For participants who responded "very low" or higher, we also asked a series of items about whether they usually receive tornado warnings from each of the following sources (0 = no, 1 = yes): television, local radio station, cell phone alert, searching the Internet, social media (e.g., Facebook or Twitter), NOAA weather radio, call/text/visit from a friend or family member, and tornado siren.

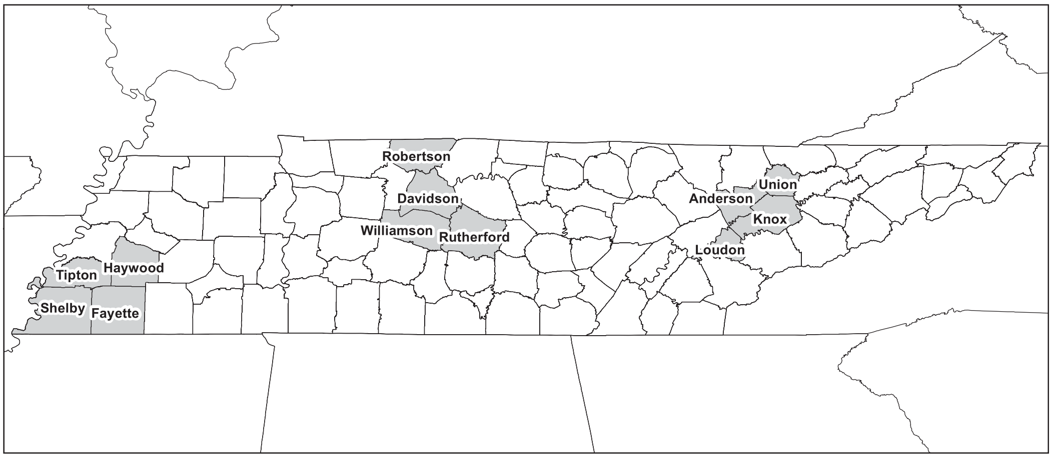

FIG. 1. Tennessee study counties.

2) INDEPENDENT VARIABLES

Independent variables included several measures of demographic characteristics, physical resources, cognitive factors, and geographic factors.

(i) Demographic characteristics

We measured gender (0 = male, 1 = female), age (years), race or ethnicity (collapsed into 1 = white or Caucasian, 2 = black or African American, 3 = other, including American Indian or Alaska Native, Asian, Hispanic or Latino, other as specified by the participant, biracial, and multiracial), and education (collapsed into 1 = high school diploma or less, 2 = some college or technical/associate's degree, 3 = college degree or more). For income, participants chose one of 12 levels for their annual gross household income, ranging from "less than \$20 000" to "\$120 000 or more"; for regression analysis, we treated income level as a continuous variable. We also measured marital status (collapsed into 1 = married or living with a long-term partner, 0 = other marital status), children in the household under age 18 (1 = yes, 0 = no), someone in the household aged 65 and older (1 = yes, 0 = no), language other than English spoken in the household (1 = yes, 0 = no), and years living in Tennessee.

(ii) Physical resources

We asked participants about three physical resources relevant to tornado warnings and safety: the type of phone they have (0 = no cell phone, 1 = cell phone but not smartphone, 2 = smartphone), their home type (0 = mobile home, 1 = apartment/condo/other, 2 = single or multifamily home), and whether their home has a basement or storm shelter on site (1 = yes, 0 = no).

(iii) Cognitive factors

We measured several cognitive or perceptual factors that may relate to tornado warnings and safety: perceived county risk to tornadoes, perceived warning accuracy, prior experience with tornadoes, self-efficacy, luck, fatalism, and understanding of tornado warnings. Table 1 summarizes corresponding survey items and response options. For regression analysis, we treated perceived county risk, luck, and fatalism as continuous variables. For understanding of tornado warnings, open-ended responses were independently reviewed and coded as correct or incorrect by two research team members, who followed a coding protocol based on the National Weather Service definition of a tornado warning (i.e., tornado has been spotted in person or observed on radar) and/or the behavior one should take during a warning (i.e., take appropriate shelter now); any differences in coding were then reviewed and reconciled.

(iv) Geographic factors

We asked participants if their residence was rural (0 = no, 1 = yes), and we recorded their county (12 possible values) and region (1 = west, 2 = middle, 3 = east) using the sampling information acquired during recruitment.

c. Analyses

We analyzed the data with bivariate statistics (SPSS 24.0) and logistic regression (STATA 14.2). To assess randomization into day and night survey versions, we conducted bivariate analyses with key independent variables, split by whether a participant was in either sample. We also used the Mann–Whitney U test and chi-square analyses to assess differences in dependent variables between day and night samples.

TABLE 1. Measurement of cognitive factors.

Factor	Survey item(s)	Response options
Perceived county risk to tornadoes	How often would you say tornadoes hit [insert participant's county name] county?	Never; Once every 50 years or longer; Once every 25 years; Once every 10 years; Once every few years; Once a year; More than once a year
Perceived warning accuracy	How accurate do you think tornado warnings are in predicting actual tornadoes touching down? Would you say they are...	Extremely inaccurate; Somewhat inaccurate; Somewhat accurate; Extremely accurate
Prior experience with tornadoes[a]	Has a tornado ever hit your home? Has a tornado ever hit a building while you were inside? Has a tornado ever hit near where you live?	Yes/No for each item
Self-efficacy	Except in extreme circumstances, my safety is under my control when a tornado threatens.	Strongly disagree; Disagree; Agree; Strongly agree
Luck	Surviving a tornado is mostly a matter of luck.	Strongly disagree; Disagree; Agree; Strongly agree
Fatalism	People die when it is their time, and not much can be done about it.	Strongly disagree; Disagree; Agree; Strongly agree
Understanding of tornado warnings	In your own words, what does a tornado warning mean?	Open-ended response

[a] Each item was asked separately, with a skip pattern for other items once a "Yes" response is given.

For logistic regression, we first used bivariate analyses to decide which independent variables should be included in the model; if a variable was significantly associated with either the day or night version of the dependent variable (chance of finding out about the warning), we retained it. Omitted variables were gender, language other than English, and self-efficacy. We then regressed each dependent variable on the same set of independent variables, clustering standard errors by county. Because of a high rate of missing data for income (15.3%), we used multiple imputation with fully conditional specification to create 10 imputed datasets for regression (Lee and Carlin 2010). We assessed the final regression models for multicollinearity and influential outliers. No problematic multicollinearity was found based on a review of variance inflation factors. For the final models, we removed two outliers each from the day and night analyses, based on Cook's D values and comparison of results with and without outliers.

2. Results

a. Sample characteristics and randomization

Table 2 presents sample characteristics by survey version and results of randomization tests. The typical participant was female, in her mid-50s, white, and with at least some college education or a technical or associate's degree. Chi-square and independent samples t tests suggest that the day and night samples are statistically equivalent on all key characteristics.

b. Chance of warning receipt

There was a statistically significant difference in the likelihood of a participant finding out about a tornado warning for the day versus night scenarios used in the survey ($U = 241\,285.50$, $p = 0.000$; Table 3). Whereas 83.7% of participants asked about a daytime warning said there was a high or very high chance that they would find out about it, only 48.3% of those asked about a nighttime warning indicated a high or very high chance of finding out.

c. Warning sources

For almost all tornado warning sources, there was a statistically significant difference in the percentage of participants who reported receiving a warning from that source during the day versus at night (Table 4), with daytime rates higher for all sources except NOAA weather radio, for which no significant difference was found. Television, for example, was a usual warning source for 74.7% of participants during the day versus 58.1% at night. The comparison for cell phone alerts was 67.9% (day) versus 61.9% (night), and finding out from a friend or family member was 66.0% (day) versus 54.0% (night).

d. Predictive models of warning receipt

1) DAY

Several demographic variables and cognitive factors were significantly associated with the chance of finding out about a tornado warning during the day (Table 5). Participants who are African American have 2.4 times

TABLE 2. Sample characteristics, by survey version.

Variable	Day % or mean (SD) (n = 939)	Night % or mean (SD) (n = 865)	p[a]
Gender, female	63.4	64.0	0.79
Age, years	56.1 (16.1)	55.1 (17.0)	0.21
Race or ethnicity			0.06
White or Caucasian	77.0	78.8	
Black or African American	17.2	17.7	
Other[b]	5.8	3.4	
Education level			0.80
High school diploma or less	28.4	27.2	
Some college or tech./assoc. degree	34.7	36.0	
College degree or more	36.9	36.8	
Income level[c]	5.5 (3.8)	5.3 (3.6)	0.41
Married or living with a long-term partner	60.2	60.7	0.86
Child under 18 in home	27.2	27.4	0.93
Household member aged 65 or older	45.1	44.5	0.79
Language other than English	7.0	5.8	0.31
Years in TN	39.4 (22.0)	39.1 (21.7)	0.77
Phone type			0.97
No cell phone	4.2	4.1	
Cell phone, not smartphone	25.2	25.7	
Smartphone	70.6	70.2	
Housing type			0.23
Mobile home	11.0	8.6	
Other (e.g., apartment, condo)	8.3	8.1	
Single or multifamily home	80.7	83.3	
Basement or storm shelter	30.4	29.5	0.43
Rural	47.3	48.0	0.77
Region			0.91
West	33.7	32.7	
Middle	31.7	32.4	
East	34.6	34.9	

[a] All p values are from chi-square analyses, except for age, years in TN, and income level, which have p values from independent samples t tests.

[b] "Other" includes American Indian or Alaska Native, Asian, Hispanic or Latino, other (specified by the participant), biracial, and multiracial.

[c] Income level of 5 = \$50 000 to less than \$60 000 annual household income; income level of 6 = \$60 000 to less than \$70 000 annual household income.

the odds of finding out than participants who are white. As income increases by one level (as measured in this study), the odds of finding out increase by 10.0%. For every additional year lived in Tennessee, there is a 1.4% increase in odds of finding out.

For cognitive factors, as perceived county risk increases by one level (as measured in this study), the odds of finding out about a tornado warning during the day increase by 13.2%. Compared to participants who perceive tornado warnings as extremely or somewhat inaccurate, those who perceive them as somewhat or extremely accurate have 2.0 and 2.9 times the odds of finding out, respectively.

2) NIGHT

For finding out about a tornado warning during the night, there were no significant associations with demographic variables. Instead, significant associations were found with cognitive factors and one geographic factor. As perceived county risk increases by one level (as measured in this study), the odds of finding out about a tornado warning during the night increase by 17.2%. Compared to participants with no prior experience with a tornado, those whose home was hit or who were in a building as it was hit by a tornado have 1.6 times the odds of finding out. Belief in the role that

TABLE 3. Chance of finding out about tornado warning.[a]

Chance	Day, % (n = 939)	Night, % (n = 865)
No chance	1.1	14.1
Very low	5.2	18.1
Low	9.9	19.5
High	40.1	25.7
Very high	43.6	22.6

[a] U = 241 285.50; p = 0.000

TABLE 4. Tornado warning source(s).

Source	Day, % (n = 939)	Night, % (n = 865)	χ^2
Television	74.7	58.1	55.94***
Cell phone alert	67.9	61.9	7.11**
Friend or family member (e.g., call, text, or visit)	66.0	54.0	26.89***
Tornado siren	60.3	48.7	24.03***
Local radio station	53.2	30.3	95.82***
NOAA weather radio	32.9	33.5	0.06
Social media (e.g., Facebook or Twitter)	29.3	24.0	6.44*
Searching the Internet	26.4	19.5	11.91**

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

luck plays in surviving a tornado, meanwhile, is associated with lower odds of finding out: as the degree of agreement that luck affects survival increases by one point, odds decrease by 18.3%. Finally, participants who live in the east region have 0.5 times the odds of finding out, compared to participants who live in the west region.

e. *Strengths and limitations*

Strengths of this study are its large sample, use of random sampling, and administration of near-identical day and night survey versions using random assignment. Results must be interpreted with caution, however, in light of study limitations. Because of nonresponse bias, participants are not necessarily representative of the general population in the 12 study counties. Also, warning receipt measures are based on day versus night scenarios, not on receipt of warnings or related information-seeking behavior during actual tornadic events happening during the day or night with the same population. Finally, we focus only on hypothetical warning receipt, not on intended behavior upon receipt of that warning; receiving a warning does not ensure that someone will then seek appropriate shelter.

4. Discussion

This study used random sampling and random assignment to compare chance of warning receipt, warning sources, and predictors of warning receipt for day versus night tornado scenarios. Over half of participants asked about a tornado warning at night said there was no or little chance that they would receive the warning. Since warning receipt is a critical factor in taking protective action during a tornado (Brotzge and Donner 2013; Lindell and Perry 2012), these individuals may be particularly vulnerable to harm or fatality from nocturnal tornadoes when such events occur. Future research would benefit from partnership with the NWS, emergency managers (EMs), and local media to examine what messages people are receiving about the potential for severe weather before they go to sleep, as well as suggestions people themselves have for how to improve warning receipt at night. These collaborative research partnerships could help address unanswered scientific questions, while also ensuring relevance and seeking input from field partners on what information would be most useful to them for designing and disseminating communications.

When looking at how warning sources differ by day versus night, this study's results suggest that there is still room to improve warning receipt via cell phone message (only 61.9% of nighttime respondents indicated receiving warnings this way) and perhaps by encouraging people to use their social networks to spread the word about tornado warnings when they are received (reported receipt through friends or family decreased from 66.0% of daytime participants to 54.9% of nighttime participants). Also, many of the sources that people identify as receiving warnings from at night (e.g., television and radio) are not designed to wake them up if sleeping; rather, people likely receive these if they are still awake or use them as secondary sources after being woken by an alert, weather radio, or severe weather. In addition, while the NWS, EMs, and local media have improved their social media presence and dissemination of warnings through such channels in recent years, this study's results suggest that a substantial portion of the public is not yet receiving these messages through social media (29.3% day, 24.0% night).

When comparing predictors of warning receipt for the day versus night, it is interesting that demographic characteristics are significantly associated with daytime but not nighttime receipt, since this may have different implications for identifying who to target in warning dissemination efforts and how. These findings for daytime are somewhat consistent with prior research (e.g., the positive association with higher income; Silver 2015), though we do not find support for associations

TABLE 5. Predictive models of high/very high chance of finding out about tornado warning.[a]

Variable	Day			Night		
	Est.[b]	SE[c]	OR[d]	Est.	SE	OR
Demographics						
Age	0.014	0.049	1.014	0.022	0.021	1.022
Age, squared	0.000	0.000	1.000	0.000	0.000	1.000
Race, white or Caucasian						
Black or African American	0.874*	0.400	2.397	−0.070	0.227	0.932
Other	−0.399	0.344	0.671	−0.692	0.491	0.500
Education, high school diploma or less						
Some college or tech./assoc. degree	0.050	0.209	1.051	−0.045	0.220	0.956
College degree or more	0.051	0.270	1.053	0.128	0.267	1.137
Income level	0.095*	0.047	1.100	0.023	0.020	1.023
Married or living with a long-term partner	−0.107	0.205	0.898	0.026	0.145	1.027
Child under 18 in home	0.175	0.236	1.191	0.281	0.193	1.325
Household member aged 65 or older	0.023	0.233	1.023	0.180	0.168	1.197
Years in TN	0.014**	0.005	1.014	−0.001	0.005	0.999
Physical resources						
Phone type, no cell phone						
Cell phone, not smartphone	0.168	0.555	1.183	0.931	0.549	2.538
Smartphone	0.435	0.430	1.545	0.865	0.601	2.376
Home type, mobile home						
Other (e.g., apartment, condo)	0.288	0.515	1.334	0.322	0.311	1.379
Single or multifamily home	−0.602	0.323	0.548	0.454	0.317	1.575
Basement or storm shelter	−0.250	0.220	0.779	0.142	0.243	1.152
Cognitive factors						
Perceived county risk	0.124*	0.058	1.132	0.158**	0.047	1.172
Perceived warning accuracy, extremely/somewhat inaccurate						
Somewhat accurate	0.698**	0.225	2.009	−0.052	0.369	0.949
Extremely accurate	1.070**	0.311	2.916	0.014	0.421	1.014
Prior experience, not nearby						
Near where live	0.030	0.144	1.030	0.074	0.153	1.077
Home or building	0.326	0.435	1.386	0.444**	0.148	1.559
Luck	0.015	0.096	1.015	−0.169*	0.082	0.845
Fatalism	−0.017	0.123	0.984	0.022	0.115	1.023
Tornado warning understanding	0.406	0.209	1.501	0.268	0.161	1.307
Geographic factors						
Rural	−0.277	0.166	0.758	−0.189	0.161	0.828
Region, west						
Middle	0.047	0.287	1.048	0.221	0.118	1.247
East	−0.201	0.263	0.818	−0.653**	0.220	0.520

[a] 0 = no/very low/low chance, 1 = high/very high chance.
[b] Est. = Parameter estimate.
[c] SE = Standard error.
[d] OR = Odds ratio.
* $p < 0.05$
** $p < 0.01$

with gender (Silver 2015) or age (Durage et al. 2014). The lack of association with some demographic characteristics may be due to our inclusion of cognitive and other factors not previously considered.

For night, meanwhile, cognitive factors (not demographics) seem most salient for predicting a high chance of receiving tornado warnings. That perceived county risk and prior experience with a tornado are positively associated with chance of warning receipt at night suggests that people with these characteristics may be more likely to pay attention to severe weather or proactively take steps to ensure they receive nighttime warnings. Future research could explore these factors in more depth, particularly with nonscenario-based designs.

It is concerning that holding a belief that luck plays a role in surviving a tornado is negatively associated with chance of nighttime receipt. People who do not have a strong sense of self-efficacy in surviving a tornado may pay less regard to warnings or fail to take simple steps to receive warnings, such as ensuring emergency cell phone alerts are activated and other potential life-saving behaviors. In-depth, qualitative research with groups who hold this belief may help shed light on how to influence related tornado safety behaviors.

That participants from east Tennessee are less likely to receive nighttime warnings than those from west Tennessee is not surprising, though this may still be an area for future research and partner collaboration. East Tennessee has a relatively lower risk of tornadoes than other regions in the state (Brown et al. 2016). Although researchers and practitioners would not want to unnecessarily raise alarms about nocturnal tornadoes in an area where they are less likely to occur, there may still be ways to improve the chance of warning receipt among this group, since the possibility of nocturnal tornadoes is still present.

Finally, although not the focus of the study, it is interesting that African American participants have a higher chance of receiving daytime warnings than white participants. It may be that African American social and family networks play a role in receiving warning information, or that the relatively higher percentage of African Americans in western, compared to eastern, Tennessee—where tornadoes are more frequent—is a factor. Also, the finding that participants who perceive warnings as more accurate are more likely to receive warnings during the day suggests a possible proclivity among this group to seek out warning information, compared to people who perceive warnings as inaccurate.

5. Conclusions

This is the first study to focus explicitly on tornado warnings at night—an important research area to develop, given the higher fatality risk that nocturnal tornadoes pose, compared to tornadoes during the day. Results suggest that people are much less likely to receive a tornado warning at night, a finding that may not be surprising but for which there was no prior empirical evidence. Also, chance of nighttime receipt does not vary by demographic characteristics in this study, meaning that certain ''groups'' of people who might be targeted by warning dissemination strategies are harder to identify. Instead, certain cognitive factors—perceived county risk and prior experience with tornadoes—may play a more prominent role in people proactively taking steps to ensure that they receive warnings at night. These cognitive factors warrant much more future study, ideally through a combination of quantitative and qualitative methods and ones that are based on actual experience, to move this field forward. Finally, new collaborative research with NWS, EMs, and local media could set an agenda for answering critical questions about how to improve warning access at night, with the public goal of reducing nighttime tornado fatalities.

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