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Examining patterns of intended response to tornado warnings among residents of Tennessee, United States, through a latent class analysis approach

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Abstract

In the past five years, the southern region of the United States has had a large number of fatal tornadoes. Previous research indicates that residents of this area may not be taking appropriate shelter. The present study uses a random sample of Tennessee residents (N = 1,126) and the latent class analysis (LCA) technique to explore discrete types of responders according to their pattern of intended behaviors when presented with a tornado warning scenario in the daytime or nighttime. LCA revealed three distinct groups in the day subsample – Tech Users, Typical Actors, and Passive Reactors – and three in the night subsample – Tech Users, Typical Actors, and Non-Reactors. Being a Tech User or Typical Actor was positively associated with intending to seek safe shelter, although being a Passive Reactor or Non-Reactor was not. Further, Tech Users/Typical Actors were seeking and obtaining more warning information from other sources compared to Passive Reactors/Non-Reactors. While few demographic variables were associated with class assignment, bivariate and multivariate analyses illustrated that cognitive factors, such as previous experience with tornadoes and perceived accuracy of warnings, are significantly associated with class membership when controlling for non-cognitive factors. The distinctions made within and between the subsamples can support the National Weather Service's efforts to better target the public with future messages about tornado safety as well as guide researchers on future studies.

Keywords: tornadoes; behavior patterns; shelter-seeking behaviors; latent class analysis

1. Introduction

The United States (U.S.) leads the world in tornadic events (Guo, Wang, & Bluestein, 2016). In 2017 alone, the National Oceanic and Atmospheric Administration's (NOAA) Storm Prediction Center (SPC) recorded 1,429 tornadoes (2018a). These severe weather events resulted in 35 deaths from 14 tornadoes and billions of dollars' worth of property damage (Miller, 2018; NOAA/SPC, 2018a; NOAA/National Centers for Environmental Information [NCEI], 2018). The southern region of the U.S. – Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, New Mexico, Oklahoma, Tennessee, and Texas (NOAA/NCEI, n.d.) – has a large number of fatal tornadoes, experiencing the most deaths in the past five years compared to other areas of the country (NOAA/SPC, 2014, 2015, 2016, 2017, 2018b). Further, 11 of the 25 deadliest tornadoes in the U.S. ever recorded were in the southern region (NOAA, n.d.).

While severe weather and tornadoes are commonplace in the southern U.S., previous research has found that appropriate response to tornado warnings by the public in this area is lacking as some regional residents are disregarding warnings, not seeking appropriate shelter, and engaging in other risky behaviors during severe weather (e.g., Balluz, Schieve, Holmes, Kiezak, & Malilay, 2000; Chaney & Weaver, 2010; Chiu et al., 2013; Comstock & Mallonee, 2005; Hammer & Schmidlin, 2002; Liu et al., 1996; Sherman-Morris, 2010). Demographical, sociological, cognitive, historical, and environmental factors that might predict individuals' likelihood to seek shelter in a tornadic event have also been uncovered in existing literature from various regions of the U.S. as well as Canada (e.g., Ahlborn & Franc, 2012; Blanchard-Boehm & Cook, 2004; Brotzge & Donner, 2013; Chaney & Weaver, 2010; Cong, Liang, & Luo, 2014; Jauernic & Van Den Broeke, 2016; Liu et al., 1996; Schmidlin, Hammer, Ono, & King, 2008; Silver & Andrey, 2014).

Meanwhile, models of protective action during events like tornadoes suggest that people may take several steps as part of their decision-making process of whether or not to seek shelter, such as gathering more information from the media, the environment, or people they know (Brotzge & Donner, 2013; Lindell & Perry, 2012). Yet, there is surprisingly little empirical research on the patterns of such behaviors that people may exhibit after receiving a warning. If such patterns exist, and there is improved understanding of which patterns relate to safe-shelter seeking and what factors are associated with each pattern, then researchers in collaboration with the NOAA's National Weather Service (NWS) and other partners could refine and target their strategies to communicate with and influence groups who share similar behavioral tendencies. This research is necessary as tornadoes are causing a substantial number of deaths and injuries in modern times despite programmatic efforts by the NWS. The 2011 tornado outbreak is a pertinent example with 316 deaths and 2,400 injuries. In their assessment, the NWS found that contributing factors included, among others,

> … individuals in the affected areas who did not respond to warnings until confirmed by more than one communication source… People in the paths of the storms who waited for visual confirmation before taking protective action…The rapid pace of the storms, which moved at 45-70 mph, giving people who waited for secondary confirmation a smaller window of time in which to take shelter… (p.1-2).

Thus, the primary objective of this study is to examine if such behavioral patterns exist among a sample of respondents with tornado warning scenarios, and, if so, whether those patterns are associated with safe shelter-seeking, and what factors are associated with pattern membership. A secondary objective is to compare patterns between warnings received during the day versus at night, given that tornadoes at night are more likely to have a fatality than those during the day and are disproportionately frequent in the southern U.S. (Ashley et al., 2008), yet studies of the distinctions between public response to daytime versus nighttime tornadoes are still rare (Mason et al., 2018).

2. Background

Gender, racial and ethnic background, residence, age, educational attainment, and income level have been connected to preparedness and response to tornado warnings in previous research. In some studies, females tended to heed warnings and, as a result, sought out safe shelter options (Sherman-Morris, 2010; Silver & Andrey, 2014) as well as tended to have plans for taking shelter in future severe weather events (Senkbeil, Rockman, & Mason, 2012). Other studies, however, have not found gender to be associated with appropriate response (e.g., Miran, Ling, & Rothfusz, 2018; Nagele & Trainor, 2012).

Race or ethnicity may create harmful barriers in severe weather situations due to language and cultural barriers (Jauernic & Van Den Broeke, 2016). Ahlborn & Franc (2012) identified that Spanish-speaking individuals in the U.S. are at greater risk for injury and death from tornadoes because they are less likely to receive and comprehend warnings and thus not respond effectively; Donner, Rodriguez, & Diaz (2012) and Senkbeil et al.(2012) had similar findings. In their study of students at a Nebraska university, Jauernic & Van Den Broeke (2017) found that international students were more likely to not have safety plans or choose a safe location during a tornado, except when they have received education prior to or shortly after arriving in the U.S. The same study also indicated that some students who had been residents of places where tornadoes are more common relied on their personal interpretation of the weather rather than heeding official warnings (Jauernic & Van Den Broeke, 2017). Geographic location in relation to impending tornadoes could also influence decisions about seeking shelter: Nagele

& Trainor (2012) found that individuals in their study who were farther than five miles from a tornado were more likely to avoid appropriate shelter. Caucasian individuals, meanwhile, have been found to have greater odds of planning for a tornado and seeking shelter as compared to people of other racial backgrounds (Cong et al., 2014; Luo, Cong & Liang, 2015).

Age as a predictor of preparedness has rendered mixed results: Senkbeil et al. (2012) found that compared to younger people (19 to 24 years old), individuals ages 35 to 44 and 55 and over were more likely to have a shelter plan before the tornado struck. However, in their post-disaster study, Chaney, Weaver, Youngblood, and Pitts (2013) determined that those in the 60 plus age group were the least likely to have participated in a tornado drill.

Households with minor children present have been positively associated with preparedness planning and proper shelter-seeking behavior (Chaney et al., 2013; Schmidlin et al., 2008). Individuals with more education and income also have been found to be more likely to prepare for tornadoes as well as take protective action in a tornadic event (Balluz et al., 2000; Brotzge & Donner, 2013; Chaney et al., 2013; Liu et al., 1996; Senkbeil et al., 2012).

Type of housing and access to safe shelter may also affect one's reaction to tornado warnings. Chaney & Weaver (2010) and Chaney et al. (2013) found that mobile or manufactured home residents are especially vulnerable to the detrimental results of tornadoes. In contrast to individuals living in permanent housing structures, mobile home dwellers were less likely to follow a safety plan regardless of whether they felt in danger. Within the mobile home resident sample, individuals who had participated in a tornado drill and those who understood the definition of a tornado warning were more likely to evacuate and pursue proper shelter during a tornado warning, which is the appropriate safety response for mobile home residents. Nonetheless, education regarding severe weather did not impact residents' choices to leave or stay in their mobile homes upon receiving a tornado warning (Chaney & Weaver, 2010). It is worth noting that the profile of a typical mobile/manufactured home resident encompasses financial and social insecurity, and the southern region has the highest percentage of mobile/manufactured home occupants in the U.S. (MacTavish, Eley, & Salamon, 2006). Regarding access to safe shelter, Balluz et al. (2000) found that individuals who did not respond appropriately to tornado warnings often lacked access to a basement or other type of appropriate shelter. Another study showed that compared to those without safe shelter, individuals with access were more likely to have a safety plan while also more likely to trust in weather officials and future warnings despite false alarms (Schultz et al., 2010).

Myths or mistaken beliefs about tornadoes may also impact response behavior. Common myths include that tornadoes cannot affect urban areas and that large buildings provide protection; mountains, hills, and rivers serve as shields from tornadoes; snow covered grounds are not susceptible to tornadoes; and overpasses are safe places for drivers to take cover in tornadoes (Donner et al., 2012; Jauernic & Van Den Broeke, 2016; Jauernic & Van Den Broeke, 2017; Klockow, Peppler, & McPherson, 2014; Ripberger et al., 2015a; Van Den Broeke & Arthurs, 2015). In their study of residents in the southern region of the U.S., Donner et al. (2012) observed that these types of myths lead some people to not seek safe shelter during a tornado.

The concept of fatalism, a psychological variable, has been considered in past research as well, though to a lesser extent than demographic ones. In two studies, it was found that when participants referenced “God’s will” or a divine power controlling their fate, they were less likely to respond to warnings appropriately (Schmidlin et al., 2008; Senkbeil et al., 2012).

Previous studies have demonstrated that the majority of the population has sufficient knowledge about tornadoes, including the definition of a tornado warning and the difference between watches and warnings (Jauernic & Van Den Broeke, 2016; Liu et al., 1996; Ripberger, Silva, Jenkins-Smith, & James, 2015a; Schultz et al., 2010). Yet, when individuals are not informed about tornadoes and communication in their region regarding severe weather events is deficient, they are less likely to take protective action when an event occurs (Donner et al., 2012; Jauernic & Van Den Broeke, 2016). The receipt of tornado warnings from multiple sources (e.g., a tornado warning for the same event from television and a siren) has been connected with appropriate shelter-seeking behaviors (Hammer, 2002; Jauernic & Van Den Broeke, 2016; Luo et al., 2015; Miran et al., 2018; Paul et al., 2015). More detailed warnings that use stronger language and specific geographical landmarks may also motivate individuals to heed warnings and avoid risky behavior (Blanchard-Boehm & Cook, 2004; Casteel & Downing, 2013; Donner et al., 2012; Jauernic & Van Den Broeke, 2016; McGee & Gow, 2012; Ripberger et al., 2015a). Nonetheless, "in order for warnings to be effective, individuals must perceive them as valid and believable" (Blanchard-Boehm & Cook, 2004). Because tornado warnings are issued by the NWS and communicated by meteorologists and weathercasters on various media sources, the level of trust that individuals place in these entities can impact their decisions to react appropriately when tornado warnings are issued; further, false alarm rates can influence how confident the public is in forecasters (Brotzge & Erikson, 2010; Donner et al., 2012; Ripberger et al., 2015b; Sherman-Morris, 2005).

Past experience with tornadoes has been shown to lead to mixed results. Afifi, Afifi, & Merrill (2014) found that individuals who experienced tornadoes which caused little to no destruction felt uncertainty and a false sense of safety in future tornadic events, resulting in not seeking shelter immediately or at all in some cases. Further, in the 2011 Joplin, Missouri, tornado that killed 162 people and destroyed sections of the city, more people who had not experienced a tornado took shelter, compared to individuals who had been part of a tornado in the past (Paul, Stimers, & Caldas, 2015). However, the magnitude of the tornadoes previously experienced by survey participants was not measured in the Paul et al. (2015) study, and one explanation could be that previously experienced tornadoes may have been weak and not impacted their risk perception. Schmidlin et al. (2008) found that previous experience was not correlated with appropriate shelter-seeking behavior. Yet, Comstock & Mallonee (2005) studied the response to two Oklahoma tornadoes four years apart and uncovered that an increased number of people sought safe shelter in the second event, demonstrating that residents' gain of knowledge and experience may have impacted their behavior during future tornado warnings; Blanchard-Boehm & Cook (2004) had similar conclusions. As noted by Jauernic & Van Den Broeke (2017), individuals who are experienced and very accustomed to tornadic activity may not seek shelter if they do not perceive an imminent threat. Similarly, Klockow et al. (2014) found that some southern U.S. residents used their experience with tornadoes and severe weather to observe the environmental signs of risk and inform their decisions to seek shelter, which the authors found to be accurate in many cases.

Overall, these factors related to individuals, their experiences, and their environments can influence risk perception – those who perceive risk as higher are often more inclined to take action and seek shelter upon warnings being issued (Donner et al., 2012; Jauernic & Van Den Broeke, 2016; Ripberger et al., 2015a).

Mostly absent from earlier research is an understanding of patterns of behavioral responses upon receiving a tornado warning. In other words, along with seeking shelter (or not), are there other actions taken when one hears about an impending tornadic event, as suggested by models of protective action (Brotzge & Donner, 2013; Lindell & Perry, 2012)? Jauernic & Van

Den Broeke (2017) examined behaviors of undergraduate students upon receiving a tornado. Their findings illustrated that many students, especially those from the U.S., needed confirmation of the event, and therefore, they sought to confirm the warnings through multiple sources (Jauernic & Van Den Broeke, 2017). Other behaviors in which they engaged included "…taking shelter, going outside to watch the storm, watching news, watching radar, or ignoring the warning" (Jauernic & Van Den Broeke, 2017, p. 135).

To understand if actions like those identified in Jauernic & Van Den Broeke (2017) group together as identifiable patterns, the present study explored discrete types of responders according to their pattern of intended behaviors when presented with a tornado warning scenario in the daytime or nighttime in a southern U.S. state using latent class analysis (LCA). We then determined if patterns of intended behavior upon receiving a tornado warning (i.e., responder type) were associated with appropriate intended response (i.e., seek safe shelter). LCA is an appropriate yet novel approach as it allows a better understanding of "the impact of exposure to patterns of multiple risks, as well as the antecedents and consequences of complex behaviors, so that interventions can be tailored to target the subgroups that will benefit most" (Pennsylvania State University, n.d., Latent Class Modeling section, para. 2). To our knowledge, LCA has not been used in prior research to determine patterns of individuals' responses, intended or actual, to tornado warnings. Uncovering the patterns of intended response and identifying the types of responders through LCA will provide empirical information to the NWS that will help them to effectively hone their messaging and education efforts to the most vulnerable individuals in potentially deadly situations.

Also lacking in the literature is individuals' responses to tornado warnings for daytime versus nocturnal events occurring in any part of the U.S. Nocturnal tornadoes place individuals at greater risk for injury and death for a few reasons: 1) sleeping can interfere with the reception of tornado warnings; 2) individuals with traditional schedules are typically indoors where sirens are not intended to be heard; and 3) nighttime events are difficult to visually detect by a lay person (Ashley, Krmenec, & Schwantes, 2008; Brotzge & Donner, 2013; Mason et al., 2018). Thus, this study also examined distinctions among these different types of daytime and nighttime responders and differentiated them by demographic, resource, geographic, and cognitive factors.

3. Methods

3.1 Participants and Sampling Procedure

The present study was part of a larger project that was approved by the University of Tennessee Institutional Review Board in January 2016. Residents from 12 counties in the West, Central, and East regions of Tennessee, a state located in the southern U.S., were the focus of the study (see Figure 1). These regions include the most populated cities in Tennessee (Memphis, Nashville, and Knoxville) and the counties including and surrounding them.

Study recruitment took place from February to July 2016. A randomly sampled list of phone numbers for landlines and cellphones from the 12 counties was obtained to recruit participants for a phone survey that utilized standard, computer-assisted, telephone interviewing technology to facilitate skip patterns, asking of day/night questions, and data entry directly into a database. Verbal informed consent was required, and participants received a $10 gift card incentive. The response rates for cell phones was slightly higher at 19.7% compared to 14.1% of landline users. The final sample for the larger project was 1,804. Of those, approximately 60% were randomly assigned to a tornado warning scenario (the focus of this study); the remaining were assigned to a tornado watch scenario. The sample size for the present study is 1,126.

Figure 1. Map of Tennessee, United States. Twelve counties in the West, Central, and East regions of Tennessee, a state located in the Southern region of the United States, were included.

Participants were randomly assigned to a daytime or nighttime version of the survey. The only difference in the items on the surveys related to wording regarding the time of day when the hypothetical tornadic events occurred (i.e., “You are home asleep on a Saturday night. You are awakened in the middle of the night and learn that the National Weather Service has issued a tornado warning for the area where you live. A tornado warning means that weather radar shows a tornado may be occurring or a tornado has been spotted in the area. Which if any of the following would you do upon learning about the warning?”). The participant responses about intended behavior in the hypothetical tornadoes presented were based on self-report (limitations of this approach are discussed in *Section 4.5*).

Though the study design intended to assign 50% of respondents to the day scenario and 50% to the night scenario, the random assignment code in the computer program used during recruitment was inadvertently programmed to assign a higher percentage to the night scenario. The final subsamples are 437 for day and 689 for night, or 38% and 62% of the combined sample, respectively.

3.2 Measures

From the larger survey, measures analyzed for this study are in five variable categories: warning-response indicators, demographic and socioeconomic characteristics, resource factors, geographic factors, and cognitive factors.

3.2.1 Warning-Response Indicators

The warning-response indicators were used to generate the latent class models. These variables provided information about participants' intended behaviors upon receiving the tornado warning. As stated, each respondent was randomly assigned to a daytime or nighttime tornado scenario and asked if they would take any of the following actions when they learned about a tornado warning:

1. Do nothing, continue on as before
2. Turn on the television or radio to find more information
3. Search the internet to find more information
4. Use an app on a smartphone or tablet to find more information
5. Look or go outside to check the weather yourself
6. Contact friends or family
7. Seek shelter in your home
8. If Yes, where in your home would you go for shelter?
9. Leave your home
10. If Yes, where would you go?
11. Pray for safety
12. Something else (specify):

Participants could respond with "yes," "no," or "I don't know," or they could refuse to answer the question. For the purposes of the LCA, items one to six were used as we were interested in the patterns of behavior taken outside of shelter-seeking. Responses of "yes" (coded 1) and "no" (coded 0) were utilized, and "I don't know" responses and refusals were coded as missing.

A new variable was also created for each of the day and night subsamples called, "appropriate response," to determine if the identified classes of responders predicted appropriate response to tornado warnings. To create this variable, two of the study authors reviewed the answers to items 7 and 8 above, in conjunction with the respondent's housing type and presence of a basement or storm shelter on their property, to determine whether or not the respondent gave an "appropriate response" in line with NOAA recommendations for tornado safety. Two examples of "appropriate response" (coded as 1) are: (1) a person in a single-family home with no basement who said they would seek shelter in an interior closet, and (2) a person in a mobile home with no storm shelter who said they would go to their relative's single-family home which has a basement. Two examples of "inappropriate response" (coded as 0) are: (1) a person in a single-family home with a basement who did not say they would go to the basement or lowest level of their home, and (2) a person in a mobile home who said they would go to the bathroom in their mobile home.

Items 11 and 12 were not used in this study. Item 11 focused on prayer, which was outside the kind of concrete, protective actions that this study focused on (e.g., actions that could be the focus of NWS communications about tornado safety). A preliminary review of responses for item 12 found that they tended to be vague (e.g., "be prepared) or to describe actions already collected through the preceding items (e.g., "call friends or family").

3.2.2 Demographic and Socioeconomic Characteristics

Once the latent class models were constructed, demographic and socioeconomic characteristics were used to describe the identified classes of responders. Gender, age, race, education, income level, marital status, years as a Tennessee resident, language other than English spoken in the home, children in the house age 18 years and younger, and adults age 65 and older in the house were examined. Age and years as a resident of Tennessee were continuous variables with respondents providing an exact number. Gender was coded female (1) and male (0). Race had three categories with white (1), black (2), and other (3), which included biracial and multiracial. Education had three levels: high school diploma or less (1); some college or technical or associate degree (2); and college graduate or higher (3). Income was categorized as a continuous variable as it had twelve levels in $10,000 increments (e.g., less than $20,000 coded as 1; $120,000 or more coded as 12). Marital status was defined as dichotomous: not married nor living with long-term partner (0) or married or living with long-term partner (1). Other dichotomous measures, with “no” (0) and “yes” (1), included: “Are languages other than English spoken in the home?,” and if children who were 18 or younger or adults 65 or older were present in the home.

3.2.3 Resource Factors

Resource factors are variables that consider resources that participants have available and might help them respond in a tornado warning. Respondents were asked the type of phone that they owned if any: no cell phone (0); cell phone but not a smartphone (1); and smartphone (2). The survey inquired about their home type as well, including mobile home (1); other which consisted of apartments and condominiums (2); and single- or multi-family house (3). Access to a basement or storm shelter at the residence was coded as no access (0) and access (1).

3.2.4 Geographic Factors

Geography was considered in three ways for this study: county, region, and rurality. The county variable had 12 categories, one for each county included (e.g., Anderson County coded as

1). Region was categorized as West (1); Middle (2); and East (3). Respondents were asked to describe the area where they live as rural, suburban, urban, or in some other way; for this analysis, the variable was recoded to nonrural (0) and rural (1).

3.2.5 Cognitive Factors

Cognitive factors in this study related to perceived risk, warning accuracy, prior experience, control, belief in protective factors, and knowledge about tornado warnings. Risk perception was gauged by the question, “How often would you say tornadoes hit {insert participant’s county name} county?,” with seven answer choices: never (1); once every 50 years or longer (2); once every 25 years (3); once every 10 years (4); once every few years (5); once a year (6); or more than once a year (7). This variable was treated as continuous for analysis.

To examine perceived warning accuracy, respondents were asked, “How accurate do you think tornado warnings are in predicting actual tornadoes touching down? Would you say they are extremely inaccurate (1), somewhat inaccurate (2); somewhat accurate (3); extremely accurate (4); or don’t know (coded as missing)?” For regression, the variable was recoded to combine the first and second categories – extremely inaccurate and somewhat inaccurate – to make three levels, though there may be some conceptual difference in the two categories, based on the data distribution and for parsimony.

Previous experience with tornadoes was measured by three items: 1) “Has a tornado ever hit your home?”; 2) “Has a tornado ever hit a building while you were inside?”; and 3) “Has a tornado ever hit near where you live?” Respondents answered “yes,” “no,” or “I don’t know.” For the purpose of the study, the three questions were used to create the prior experience variable, which was coded as not nearby (0); near where I live (1); and hit home or building (2).

The ability to control one’s outcome in tornadic situations was measured in three ways: 1) Self-efficacy – “Except in extreme circumstances, my safety is under my control when a tornado threatens.”; 2) Luck – “Surviving a tornado is mostly a matter of luck.”; and 3) Fatalism – “People die when it is their time and not much can be done about it.” Possible responses were strongly disagree (1); disagree (2); agree (3); strongly agree (4); or don’t know (coded as missing). The self-efficacy variable was reverse coded for the analysis.

Three questions measured belief in the ability of the geographic landscape or built environment to protect nearby places from tornadoes. Respondents were asked, “To what extent do you think hills protect nearby places from tornadoes, if at all? Would you say not at all (1), somewhat (2), very much (3), completely (4), or don’t know (coded as missing)?” The same question was asked regarding bodies of water like rivers and lakes and tall buildings in cities.

Knowledge of tornado warnings was assessed with a single, open-ended question: “In your own words, what does a tornado warning mean?” Then, two research team members used a coding protocol grounded by the NWS’s explanation of 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). The differences in coding were reviewed and reconciled by the team members. The knowledge of tornado warnings was then created: incorrect (0) and correct (1). Of note, the knowledge question was asked before the hypothetical scenario was read.

3.4 Data Analyses

The key analyses for this study included descriptive and bivariate statistics, LCA, binary logistic regression, and multinomial logistic regression. As a first step, SPSS (25.0) was used to generate descriptive statistics. A missing data analysis was also conducted in SPSS on the independent variables used in each of the research questions. All but one variable had less than five percent missingness, which is typically considered trivial to analysis (Schafer, 1999). Income had 14.2 percent missingness, and multiple imputation with fully conditional specification to generate 10 imputed datasets was used to handle this issue (Allison, 2002; Lee & Carlin, 2010). We assessed adequacy of randomization between the day and night subsamples by conducting chi-square analyses for categorical variables and t-tests for continuous variables. We performed LCA using Mplus (8.0) to determine if discrete types (also known as classes or subgroups) of responders existed and, if subgroups emerged, to ascertain the size and demographics of each. LCA is a latent variable modeling technique that measures at least two categorical indicators (observed variables) to uncover homogenous classes within a population (Collins & Lanza, 2010). Described in the previous section, the variables used in the LCA were the warning-response indicators 1 to 6 (listed in *3.2.1).* Analysis was conducted separately for the day and night subsamples, as we were interested in potential differences between response patterns by timing of the warning.

For the present study, we conducted an exploratory LCA as there were no hypotheses about the number of potential classes that might surface. Thus, models with one to five classes were estimated and examined for fit. To determine the best-fitting model, four criteria were used as recommend by Geiser (2013). First, the parametric bootstrapped likelihood ratio test (BLRT) indicated if a model was significant ($p < .05$) and performed better than the previous model. Then, the sample-size adjusted standardized Bayesian information criteria (SSABIC) from each model (one to five classes) were plotted; ideally, the best-fitting model had the lowest SSABIC. Upon choosing the model, the mean probabilities of the class membership table were assessed, where 0.8 to 0.9 on the diagonal was optimal for each class. Finally, entropy was examined.

Entropy assesses for quality of the classification with values close to 1 indicting high accuracy. Once the best fitting-model was finalized, the mean class probabilities and probable class assignment for each were imported from Mplus to SPSS to determine the characteristics of each class. We then used chi-square and ANOVA tests to investigate initial bivariate differences among classes.

To determine if class membership predicts appropriate response, SPSS was also used to conduct two binary logistic regressions (day and night subsamples). Here, we used the class assignment into each group from the LCA results as the independent variable and appropriate response to a tornado warning ("yes" or "no") as the dependent variable.

We used multinomial logistic regression to examine possible predictors of belonging to each LCA group, again for day and night subsamples. The information obtained from this analysis will be helpful in targeting individuals for education about proper safety procedures during a tornado warning. To construct multivariate models, Hosmer, Lemeshow, & Sturdivant's (2013) variable selection process was followed. First, we conducted a series of bivariate analyses in SPSS (25.0) to assess each independent variable's relationship with the identified classes for each subsample: Pearson chi-square test for categorical variables; Kruskal-Wallis for ordinal variables with four levels or less; and simple logistic regression for continuous and ordinal variables with five or more levels. The cutoff p-value to be included as a candidate in the multivariate model was $p < .25$ (Hosmer et al., 2013), with the exception of language other than English spoken in the home, which was omitted due to quasi-complete separation. Using Stata (15), we entered all variables from the first step into the model and went through several iterations as we excluded variables of little influence and tested variables that had been initially excluded (Hosmer et al., 2013). Assumptions of non-problematic multicollinearity were met;

when each independent variable was regressed against all other independent variables, all tolerance values were above .25. For the final models, two outliers were removed from the day subsample, and three were removed from the night subsample, after examining Cook's D and standardized residual values, and comparing results with and without outliers.

4. Results

4.1 Sample Characteristics

Characteristics for the day (*n* = 437) and night (*n* = 689) subsamples are in Table 1. The profile of the average respondent in both subsamples was a female in her mid-fifties with an income of at least $50,000 with at least some college education. Most respondents were married or in a long-term relationship with no children under 18 residing in the home. The majority had access to smart phones, while only about 30 percent had a basement or storm shelter readily available. Most had correct knowledge of the tornado-warning definition. Nearly half of respondents had experienced a tornado nearby their homes.

The chi-square and independent samples t-tests revealed that the day and night subsamples are statistically equivalent on most characteristics, but they differ in terms of race, years as a Tennessee resident, housing type, and rurality. The day sample was more racially or ethnically diverse than the night sample, whereas the night sample resided in Tennessee longer. The night sample had more respondents residing in single- or multi-family houses compared to the day sample. Additionally, the night sample respondents more often designated their location "rural" compared to the day sample respondents. Each of these variables was thus included or assessed for significance in other bivariate and multivariate analyses in this study.

Table 1
Sample Characteristics, by survey version

Variable	Day % or Mean (SD) (n=437)	Night % or Mean (SD) (n=689)	p^a
Gender, female	62.2	65.3	0.30
Age, years	54.3 (16.8)	56.1 (17.0)	0.07
Race or ethnicity			**0.003**
White or Caucasian	74.6	79.4	
Black or African American	18.1	17.6	
Other[b]	7.3	3.0	
Education level			0.17
High school diploma or less	30.6	27.0	
Some college, or tech/assoc. degree	32.3	37.6	
College degree or more	37.1	35.4	
Income level[c]	5.3 (3.8)	5.3 (3.5)	0.06
Married or living with a long-term partner	59.6	60.7	0.53
Children under 18 in home	29.6	27.5	0.45
Household member age 65 or older	43.5	46.6	0.32
Primary language other than English	8.1	5.8	0.14
Years in Tennessee	37.0 (22.0)	39.8 (22.0)	**0.04**
Phone type			0.05
No cell phone	3.2	4.7	
Cell phone, not smartphone	22.1	27.2	
Smartphone	74.7	68.1	
Housing type			**0.02**
Mobile home	12.3	8.3	
Other (e.g., apartment, condo)	9.3	6.7	
Single or multi-family home	78.5	85.0	
Basement or storm shelter	29.9	30.2	0.89
Rural	44.5	51.8	**0.01**
Region			0.96
West	31.4	32.1	
Middle	32.3	31.8	
East	36.4	36.1	

[a] All *p*-values are from chi-square analyses; except for age, years in Tennessee, and income level, which have *p*-values from independent samples t-tests. Bold indicates significance at $p < 0.05$ level. [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.

4.2 Latent Class Analysis

Upon conducting the LCA, authors formed a quasi-decision tree (see Figure 2) to assess the behavior of respondents and identify subgroups. The first area of consideration was the self-indication of action behavior: Did they do anything upon receiving a warning? Next, the authors contemplated the sources used for acquiring additional information. Television and radio and looking outside were considered more traditional forms of receiving information while using the internet and phone applications were considered modern technology avenues. Finally, contact with friends and family was treated as a separate behavior or action as respondents may have been contacting them to gain and/or share information about a potential tornado.

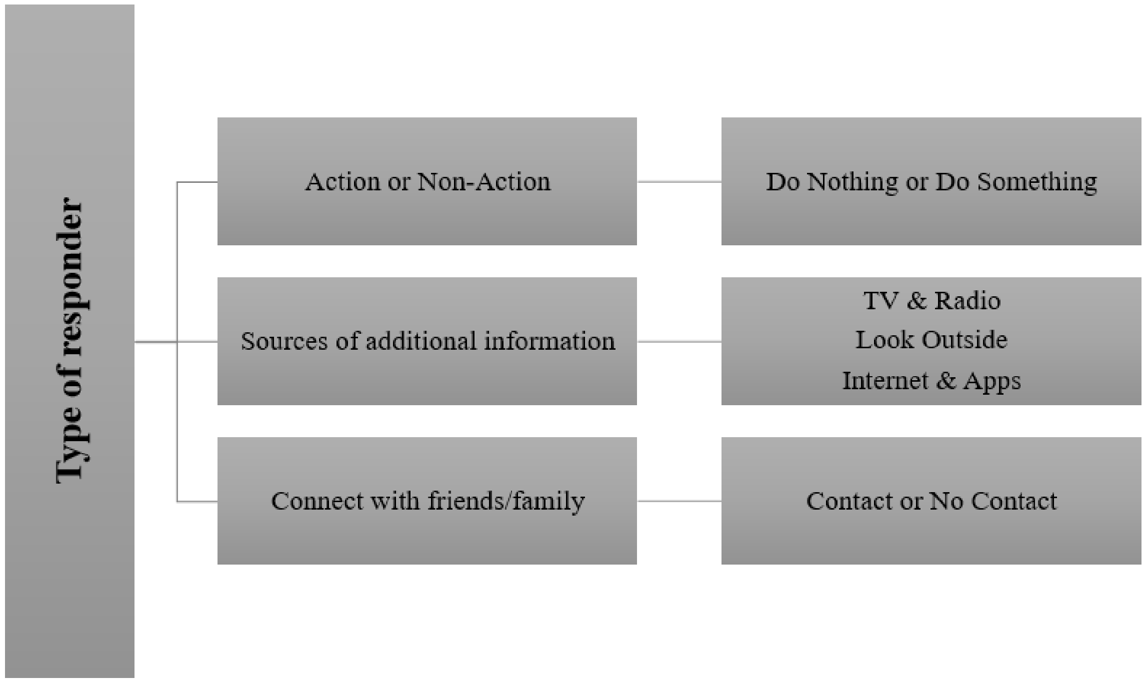


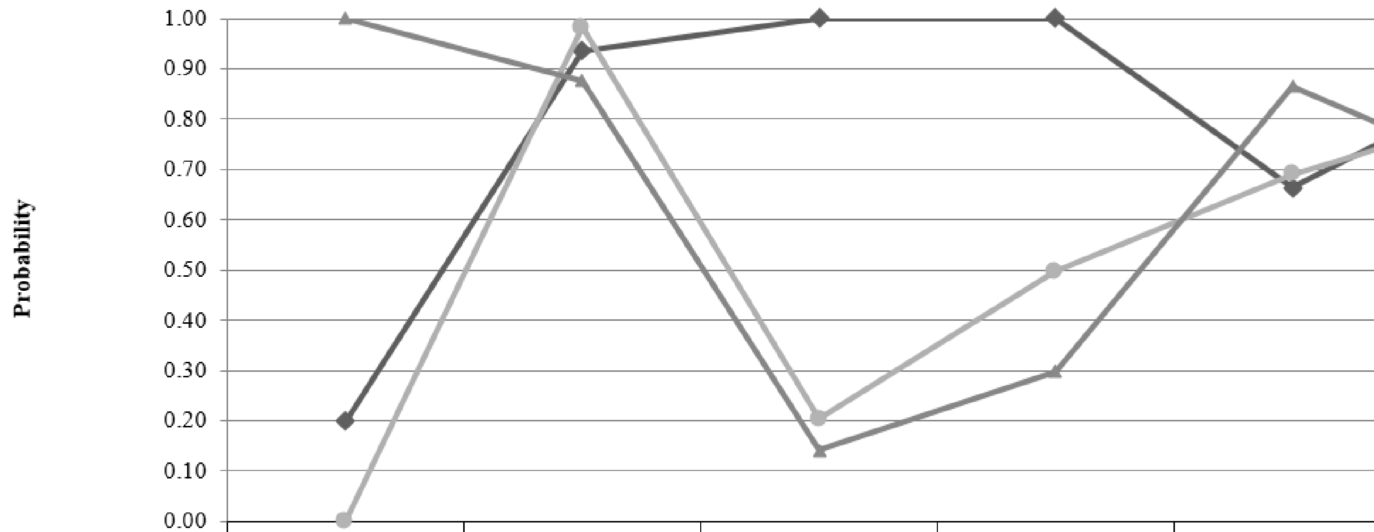
Figure 2. Decision tree related to identifying subgroups.

4.2.1 Day Sample Results

The best fitting model for the day subsample consisted of three classes (SSABIC = 2682.06, BLRT = 32.84, $p < .001$, and Entropy = 0.85). The classes were labeled: Tech Users, Typical Actors (by which we mean, typical or most common in this study), and Passive Reactors. Probabilities for class membership were 0.76 for Tech Users, 0.99 for Typical Actors, and 1.0 for Passive Reactors. Tech Users made up 29% (n = 128) of the day subsample, while 54% were assigned to Typical Actors (n = 237) and 17% to Passive Reactors (n = 72). Probabilities indicate estimates of the most likely class assignment for each respondent, and each respondent can only be assigned to one class in the final class counts and proportions analysis (Geiser, 2013).

The probabilities for the intended warning-response indicator variables are found in Figure 3. The main differences in the day subsample classes related to technology and doing nothing upon receiving a tornado warning. Passive Reactors were most likely to say they would take no action upon receiving a tornado warning. Tech Users and Typical Actors had a near opposite response, initially indicating that they would likely take some kind of action when learning about an impending tornado. While all classes were extremely likely to turn on the television to get more information about the weather event, the classes contrasted in the internet and app categories. Using the internet and an app on a smartphone to learn more about the tornado warning were extremely probable responses for Tech Users, whereas Typical Actors and Passive Reactors were much less likely to utilize these types of technology. Additionally, Tech Users and Typical Actors were more likely than Passive Reactors to contact friends and family upon receiving a tornado warning. However, Passive Reactors still had a moderate likelihood (0.66) of intending to engage in some kind of personal communication with friends and family.

Table 2 provides class characteristics of day subsample. Post-hoc, bivariate analyses revealed statistically significant differences among classes for the day subsample in the following characteristics: age, language, years residing in Tennessee, phone type, and region. As presented in *Section 4.4*, however, several of these associations were no longer found when class membership was analyzed with multivariate techniques.



	Do nothing	Turn on TV & radio	Seek info on internet	Seek info on app	Look outside
Tech Users	0.20	0.94	1.00	1.00	0.66
Typical Actors	0.00	0.98	0.20	0.50	0.69
Passive Reactors	1.00	0.88	0.14	0.30	0.87

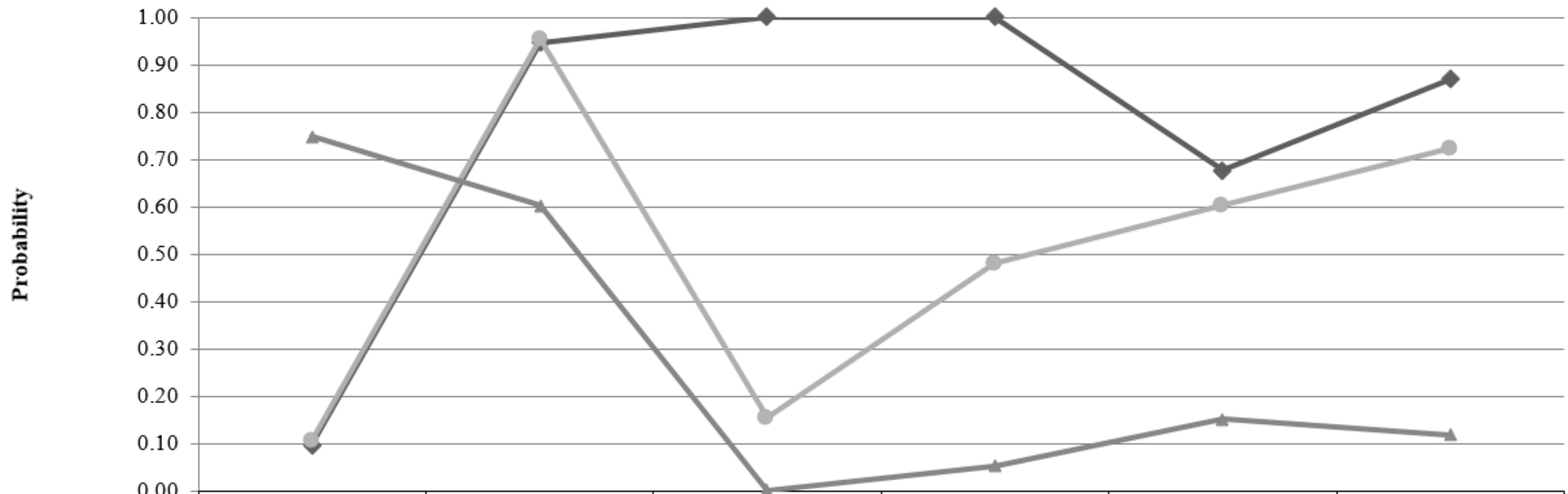
Figure 3. Day subsample probabilities for the intended warning response indicators

4.2.2 Night Sample Results

Like the day subsample, the night subsample was fitted best to the three-class model (SSABIC = 4305.44, BLRT = 38.44, $p < .001$, and Entropy = .82). Based on the results, labels were assigned to each class: Tech Users, Typical Actors, and Non-Reactors. Class membership probabilities were .80 for Tech Users, .97 for Typical Actors, and .84 for Non-Reactors. The composition of the classes was 28% in Tech Users (n = 192), 68% in Typical Actors (n = 471), and 4% in Non-Reactors (n = 26).

Figure 4 illustrates the probabilities for the intended warning-response indicators. The night subsample classes had similarities to the day subsample, but there were important distinctions related to the third class, in particular: Passive Reactors (day) and Non-Reactors (night). While there was a slightly less probability to do nothing in this third class compared to the day subsample's third class, these respondents were not as likely to respond in any other way upon receiving a tornado warning – meaning they are less probable to seek out additional information from any source (other than television or radio, in some cases) or contact family and friends.

Statistically significant differences among class characteristics (see Table 2), via bivariate analyses, included age, marital status, children under 18 in the household, adults over 65 in the household, years residing in Tennessee, and phone type. As with the day subsample, however, several of the associations were no longer found in multivariate analysis, as presented in *Section 4.4*.



	Do nothing	Turn on TV & radio	Seek info on internet	Seek info on app	Look outside	Contact friends & family
Tech Users	0.10	0.95	1.00	1.00	0.68	0.87
Typical Actors	0.11	0.95	0.15	0.48	0.60	0.72
Non-Reactors	0.75	0.60	0.00	0.05	0.15	0.12

Figure 4. Night subsample probabilities for the intended warning response indicators

Table 2
Class Characteristics, by survey version

Variable	Day % or Mean (SD)				Night % or Mean (SD)			
	TU[a]	**TA**[b]	**PR**[c]	***p***[e]	**TU**	**TA**	**NR**[d]	***p***[e]
Gender, female	57.8	63.7	65.3	0.46	64.1	65.4	72.0	0.73
Age, years	46.9 (17.1)	56.8 (15.6)	59.1 (16.4)	**<0.001**	48.7 (17.5)	58.6 (15.7)	66.4 (17.9)	**<0.001**
Race or ethnicity				0.43				0.94
White or Caucasian	74.4	74.9	73.9		78.9	79.6	80.0	
Black or African American	15.2	18.6	21.7		17.3	17.8	16.0	
Other[f]	10.4	6.5	4.3		3.8	2.6	4.0	
Education level				0.68				0.90
High school diploma or less	32.3	28.4	34.7		27.1	27.0	26.9	
Some college or tech/assoc. degree	28.3	34.5	31.9		35.1	38.3	42.3	
College degree or more	39.4	37.1	33.3		37.8	34.7	30.8	
Income level[g]	5.8 (4.2)	5.2 (3.7)	4.8 (3.7)	0.22	5.1 (3.6)	5.5 (3.5)	4.4 (3.2)	0.24
Married or living w/ a long-term partner	58.7	63.2	49.3	0.11	56.7	64.5	40.0	**0.01**
Children under 18 in home	37.8	27.2	22.5	**0.04**[h]	41.1	22.9	11.5	**<0.001**
Household member age 65 or older	34.6	47.2	47.2	0.06	30.5	51.6	73.1	**<0.001**
Primary language other than English	14.2	6.0	4.2	**0.01**	8.9	4.9	0.0	0.06
Years in Tennessee	31.0 (21.5)	39.1 (22.0)	41.1 (20.8)	**<0.001**	33.6 (19.4)	41.8 (22.3)	47.5 (25.2)	**<0.001**
Phone type				**0.001**				**<0.001**
No cell phone	0.8	4.7	2.8		1.6	5.6	11.5	
Cell phone, not smartphone	13.3	22.9	35.2		13.5	32.2	38.5	
Smartphone	85.9	72.5	62.0		84.9	62.2	50.0	
Housing type				**0.04**[h]				0.06
Mobile home	11.1	10.3	20.8		9.5	7.9	7.7	
Other (e.g., apartment, condo)	13.5	7.3	8.3		11.1	4.9	7.7	
Single or multi-family home	75.4	82.5	70.8		79.5	87.2	84.6	
Basement or storm shelter	31.7	31.6	20.8	0.19	31.9	29.7	26.9	0.80
Rural	39.8	47.0	44.3	0.43	49.2	53.2	46.2	0.55
Region				**0.02**				0.06
West	25.8	33.3	34.7		27.1	34.4	26.9	
Middle	35.2	27.4	43.1		29.2	33.1	26.9	
East	39.1	39.2	22.2		43.8	32.5	46.2	

[a] TU = Tech Users. [b] TA = Typical Actors. [c] PR = Passive Reactors. [d] NR = Non-Reactors. [e] All *p*-values are from chi-square analyses; except for age, years in Tennessee, and income level, which have *p*-values from ANOVA. Bold indicates significance at $p < 0.05$ level. [f] Other includes American Indian or Alaska Native, Asian, Hispanic or Latino, other (specified by the participant), biracial, and multiracial. [g] Income level of 4 = $40,000 to less than $50,000; 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. [h] Z-tests to compare column proportions revealed there were no

practically significant differences between any of the classes related to the children in household variable or the home-type variable.

4.3 Binary Logistic Regression

To analyze the relationship between the type of responder in each subsample and whether they intended to seek out appropriate shelter upon receiving a tornado warning, we employed binary logistic regression, which allows the comparison of odd ratios. Results are reported in Table 3. In the day subsample, the odds of Tech Users (p = .002) and Typical Actors (p < .001) seeking shelter were significantly higher than Passive Reactors, while no differences existed between Tech Users and Typical Actors (p = .695). Findings were similar in the night subsample: Tech Users (p = .001) and Typical Actors (p < .001) had considerably increased odds of seeking shelter compared to Non-Reactors. As before, there was no statistically significant difference between Tech Users and Typical Actors (p = .124).

Table 3
Relationship between Class & Shelter-Seeking Intentions, by survey version

Class	**Day**				**Night**			
	Est.[a]	SE[b]	OR[c]	95% CI[d]	Est.	SE	OR	95% CI
TU[e] vs. PR[f] (day)/NR[g] (night)	**0.96**	0.31	2.62	1.42, 4.80	**1.46**	0.44	4.32	1.82, 10.24
TA[h] vs. PR (day)/NR (night)	**1.06**	0.28	2.88	1.66, 4.96	**1.77**	0.42	5.89	2.57, 13.53
TU vs. TA	-0.10	0.25	0.91	0.56, 1.48	-0.31	0.20	0.73	0.49, 1.09

[a] Est. = parameter estimate. [b] SE = standard error. [c] OR = odds ratio. [d] CI = Confidence Interval for the OR. [e] TU = Tech Users. [f] PR = Passive Reactors. [g] NR = Non-Reactors. [h] TA = Typical Actors
Bold indicates significance at $p < 0.05$ level.

4.4 Multinomial Logistic Regression

Multinomial logistic regression was used to predict the characteristics of individuals who might be assigned to the identified classes. Analyses were performed separately for the day and night subsamples with Typical Actors as the reference group. Results are presented in Tables 4 and 5.

4.4.1 Day Sample Results

For the day subsample (Table 4), only two factors were associated with a greater chance of being a Tech User than a Typical Actor, both cognitive: greater belief in the role of luck (p = .000) and greater belief in protection from water (p = .005).

Several factors, meanwhile, were associated with a greater chance of being a Passive Reactor than a Typical Actor. Of these, the non-cognitive factors were not being married or living with a long-term partner (p = .001), living in a mobile home (versus a single- or multi-family home; p = .006), and being a resident of Middle (versus West) Tennessee (p = .011). The cognitive factors were perceiving tornado warnings as extremely or somewhat inaccurate (versus extremely accurate; p = .032), not having prior experience with a tornado (versus near one's home, p = .015; versus hitting one's home or a building while in it, p = .041), and a greater sense of fatalism (p = .010).

Table 4
Multinomial logistic regression model to predict class membership, day subsample (n=435)[a]

Variable	Tech Users				Passive Reactors			
	Est.[b]	SE[c]	OR[d]	95% CI[e]	Est.	SE	OR	95% CI
Age	-0.05	0.05	0.95	0.87, 1.05	0.02	0.06	1.02	0.91, 1.14
Age, squared	0.00	0.00	1.00	1.00, 1.00	0.00	0.00	1.00	1.00, 1.00
Race or ethnicity, White/Cauc.								
Black/African American	-0.19	0.49	0.83	0.32, 2.14	-0.33	0.49	0.72	0.27, 1.88
Other[f]	0.29	0.71	1.33	0.33, 5.37	-0.20	0.82	0.82	0.16, 4.09
Married or living w/long-term partner	-0.18	0.33	0.84	0.43, 1.61	-0.88**	0.27	0.41	0.25, 0.70
Phone type, no cell phone								
Cell phone, not smartphone	1.33	1.12	3.77	0.42, 33.83	2.22	1.14	9.21	0.98, 86.22
Smartphone	1.84	0.99	6.27	0.89, 43.96	1.75	0.96	5.74	0.88, 37.54
Housing type, mobile home								
Other (e.g., apt., condo)	-0.01	0.60	0.99	0.31, 3.17	-0.89	0.53	0.41	0.15, 1.15
Single or multi-family home	-0.50	0.36	0.61	0.30, 1.22	-0.98**	0.36	0.38	0.19, 0.76
Basement or storm shelter	0.12	0.29	1.13	0.64, 2.00	-0.03	0.37	0.97	0.47, 2.03
Region, West								
Middle	0.35	0.38	1.42	0.68, 2.97	1.01*	0.40	2.76	1.27, 6.01
East	0.27	0.30	1.31	0.72, 2.37	-0.47	0.35	0.63	0.31, 1.25
Perceived county risk	0.09	0.10	1.09	0.89, 1.34	0.15	0.16	1.16	0.84, 1.59
Perceived warning accuracy, extremely/somewhat inaccurate								
Somewhat accurate	-0.35	0.50	0.71	0.26, 1.89	-0.70	0.43	0.50	0.22, 1.15
Extremely accurate	-0.09	0.49	0.91	0.35, 2.40	-1.30*	0.61	0.27	0.08, 0.89
Prior experience, not nearby								
Near where I live	-0.18	0.37	0.84	0.40, 1.75	-1.04*	0.43	0.35	0.15, 0.82
Hit home or building	-0.22	0.43	0.80	0.34, 1.87	-1.53*	0.75	0.22	0.05, 0.94
Efficacy, reverse scored	0.28	0.16	1.33	0.96, 1.83	0.29	0.18	1.34	0.94, 1.89
Luck	0.59***	0.14	1.81	1.38, 2.38	0.13	0.20	1.14	0.77, 1.68
Fatalism	-0.08	0.18	0.92	0.64, 1.32	0.40*	0.16	1.50	1.10, 2.04
Belief in protection by water	0.38**	0.13	1.46	1.12, 1.90	-0.24	0.33	0.78	0.41, 1.49
Tornado warning knowledge	-0.18	0.33	0.84	0.44, 1.59	-0.50	0.46	0.60	0.24, 1.49

[a] Reference group is Typical Actors. [b] Est. = Parameter estimate. [c] SE = Standard error. [c] OR = Odds ratio. [e] CI = Confidence interval for the OR. [f] Other includes American Indian or Alaska Native, Asian, Hispanic or Latino, other (specified by the participant), biracial, and multiracial. * $p < .05$ ** $p < .01$ *** $p < .001$

4.4.2 Night Sample Results

For the night subsample (Table 5), several associations were found with having a greater chance of being a Tech User than a Typical Actor. Of these, the non-cognitive factors were, compared to having no cell phone, having a cell phone but not a smartphone (p = .039) or having a smartphone (p = .001); living in an "other" home type (e.g., apartment or condo; versus mobile home; p = .011); and being a resident of East (versus West) Tennessee (p = .002). Cognitive factors were having prior experience with a tornado hitting one's home or a building while inside (versus no prior experience; p = .031) and having incorrect knowledge of what a tornado warning means (p = .044).

Only a lower belief in protection by water, meanwhile, was associated with a greater chance of being a Non-Reactor than a Typical Actor (p = .005). No other statistically significant associations for this comparison were found.

4.5 Study Limitations

Limitations of this study should be considered when interpreting results. First, due to nonresponse bias, participants may not represent the general population of the study counties. Second, scenarios measure intended behavioral response, not actual behavior during a tornado. Third, intended behaviors were asked as a series of yes/no items for each, rather than asking what a person would do chronologically. Fourth, this study's measure of "appropriate response", while grounded in NOAA guidelines for tornado safety, could not account for how tornado proximity influences the appropriateness of response, an important factor noted by Miran, Ling, Gerard, & Rothfusz (2018). Fifth, responses were based on self-report, and it is possible that participants may have chosen responses that were socially desirable. Finally, regarding previous experience with tornadoes, the study does not consider severity of past tornadoes experienced by the participants – only if they have experienced a tornado and the proximity of the event.

Table 5
Multinomial logistic regression model to predict class membership, night subsample (n=686)[a]

Variable	**Tech Users**				**Non-Reactors**			
	Est.[b]	SE[c]	OR[d]	95% CI[e]	Est.	SE	OR	95% CI
Age	-0.03	0.04	0.97	0.89, 1.05	-0.07	0.08	0.94	0.80, 1.09
Age, squared	0.00	0.00	1.00	1.00, 1.00	0.00	0.00	1.00	1.00, 1.00
Phone type, no cell phone								
Cell phone, not smartphone	1.81*	0.88	6.12	1.09, 34.24	-0.30	0.84	0.74	0.14, 3.80
Smartphone	2.74**	0.82	15.48	3.10, 77.47	-0.18	0.80	0.83	0.17, 4.03
Housing type, mobile home								
Other (e.g., apt., condo)	0.86*	0.34	2.36	1.21, 4.61	1.84	1.47	6.30	0.35, 112.57
Single or multi-family home	-0.03	0.23	0.97	0.62, 1.53	0.79	1.09	2.20	0.26, 18.77
Region, West								
Middle	-0.12	0.17	0.89	0.63, 1.25	0.08	0.72	1.08	0.26, 4.46
East	0.73**	0.23	2.07	1.32, 3.25	0.27	0.56	1.31	0.43, 3.95
Perceived county risk	-0.07	0.05	0.93	0.84, 1.04	-0.14	0.18	0.87	0.61, 1.23
Perceived warning accuracy, extremely/somewhat inaccurate								
Somewhat accurate	0.20	0.34	1.22	0.63, 2.36	0.04	0.90	1.04	0.18, 6.03
Extremely accurate	-0.10	0.31	0.90	0.49, 1.67	-1.42	0.94	0.24	0.04, 1.52
Prior experience, not nearby								
Near where I live	0.26	0.22	1.30	0.84, 2.00	-0.39	0.40	0.68	0.31, 1.49
Hit home or building	0.65*	0.30	1.92	1.06, 3.47	-1.41	1.26	0.24	0.02, 2.90
Belief in protection by water	0.12	0.10	1.13	0.93, 1.36	-0.94**	0.33	0.39	0.21, 0.75
Tornado warning knowledge	-0.32*	0.16	0.73	0.53, 0.99	-0.41	0.50	0.66	0.25, 1.76

[a] Reference group is Typical Actors. [b] Est. = Parameter estimate. [c] SE = Standard error. [c] OR = Odds ratio. [e] CI = Confidence interval for the OR. * $p < .05$
** $p < .01$

5. Discussion and Conclusions

This is the first study to examine patterns of behavioral response to tornado warnings using LCA modeling techniques. Our analysis of respondents randomly assigned to warning scenarios (day or night) found three types of responders for each—Tech Users, Typical Actors, and Passive Reactors for daytime scenarios, and Tech Users, Typical Actors, and Non-Reactors for nighttime scenarios. We found that being a Tech User or Typical Actor was positively associated with intending to seek safe shelter, while being a Passive Reactor or Non-Reactor was not, and that this effect was markedly larger for the night sample. A notable difference between Tech Users/Typical Actors and Passive Reactors/Non-Reactors is that the former seem to be (in the scenarios) seeking and obtaining more warning information from other sources—television, radio, social media, the internet, and possibly family and friends. This resonates with recent literature that the more warning sources a person has, at least in some settings, the more likely they are to take protective action (Luo et al., 2015).

It is interesting to compare sizes of the identified classes. While the percentage of respondents classified as Tech Users was similar (29% day, 28% night), the size of Typical Actors increased at night (54% day, 68% night). The size of the third class, meanwhile, decreased—from 17% in Passive Reactors by day, to only 4% in Non-Reactors at night. Given the greater risk of a fatality from nighttime than daytime tornadoes, and the relatively higher prevalence of nighttime tornadoes in the southern U.S. where this study was conducted, this result can be seen as encouraging in some ways—if people receive a warning at night (as in the scenario used) they may be more likely to take action and gather information as part of their decision-making process, which is a key part of theoretical models of protective action (Brotzge & Donner, 2013; Lindell & Perry, 2012). Pairing these results with those from Mason et al.

(2018) suggests that the NWS and their media and emergency manager partners may want to prioritize new ways of trying to make sure people receive warnings at night. For example, if severe weather at night is a possibility, evening media broadcasts may want to encourage people to ensure their cell phones are charged, turned on, and near their bedside, as well as encourage people to spread the word to their family and friends. If people actually receive a nighttime warning, our results suggest that they may be likely to take some kind of additional action.

While some non-cognitive factors (demographic, resource, or geographic) were associated with class membership, especially in bivariate analyses, cognitive factors also play an important role and have relationships with class membership that persist in a multivariate analysis when non-cognitive factors are controlled for. Since being a Tech User or Typical Actor (day or night) was associated with protective action, we focus the discussion here on factors associated with being a Passive Reactor (day) or Non-Reactor (night), since members of these groups were found most at risk of not seeking safe shelter in the scenarios used in this study.

For the day, we found results for warning accuracy and prior experience that are similar to those in prior literature on how these variables relate to safe shelter seeking (e.g., Blanchard-Boehm & Cook, 2004). Since perceiving warnings as less accurate is associated with being a Passive Reactor, the NWS may want to adjust or increase its education efforts around this issue. Through research partnership with the NWS, future studies could help advance this via in-depth qualitative research, in particular, with people who view warnings as less accurate. Topics could examine why or how these perceptions formed and what people's own perspectives are on ways to influence these views. Similarly, for further understanding or addressing the role prior experience plays in taking action in response to a tornado warning, there may be means to influence people's risk through narratives of other people's prior experience. Passive Reactors indicated that they would contact family and friends in the event of a tornado warning. Thus, NWS may consider adding or increasing messages that encourage people who have prior experience to reach out to Passive Reactors to share their past history and knowledge related to tornadoes. Future research regarding the influence of family and friends on non-shelter-seeking individuals is needed. Also, Passive Reactors were found to have a greater sense of fatalism – the belief that if it is one’s time to die, then no safety measures will be helpful. While we did not inquire about religion specifically, this finding may be related to the high prevalence of religious individuals in the South (Pew Research Center, 2018). Examining the relationships between religion, fatalism, and shelter-seeking behavior as well as qualitative inquiries with religious individuals to uncover factors and strategies that might provoke them to take shelter during a tornadic event are potential directions for forthcoming studies.

For the night, the finding of a role of belief in protection from tornadoes by water is surprising—that Non-Reactors have a lower belief in this than Typical Actors. It may be that there is an interaction with geography that helps explain this relationship. While this result was unexpected, it suggests the NWS still has work to do in dispelling myths related to the geographic landscape (e.g., buildings, water, and mountains). Messages during weather broadcasts that provide examples of tornadoes that have impacted these locations in the past might be useful in reminding all individuals that tall buildings, bodies of water, and mountains do not provide protection.

Previous studies have found differences in shelter-seeking by demographics (e.g., gender, income, and education). However, the present study identified few variances in these categories. While mediation was not tested, perhaps patterns of behaviors were uncovered that mediate the influence of demographics. Further, in the present study, more emphasis was placed on a range of cognitive factors, which are less visible and more difficult for the NWS to target. To make a difference in the future, these findings call for increased partnerships with psychology and communications to engage in multidisciplinary research to better understand cognitive factors and appropriate shelter-seeking behavior.

Finally, LCA is a powerful technique for identifying subgroups of people in a sampled population, yet one that is little used in the tornado hazard literature to date. Future research of actual response to tornadic events should consider asking questions and designing studies and measures in ways amenable to LCA.

The present study sought to address a gap in the literature related to patterns of behavioral responses upon receiving a tornado warning based on models of protective action (e.g., Brotzge & Donner, 2013). Our study identified three discrete types of responders in both the day and night subsamples. While the majority of participants intended to seek shelter and access information about warnings through traditional and modern modes of technology, two groups were identified that require more attention by NWS and in future research: Passive Reactors in the day subsample and Non-Reactors in the night subsample. Overall, individuals in these groups indicated that they would do nothing upon receiving a tornado warning. The distinctions made within and between the subsamples can provide direction to NWS on how to better target these individuals with future messages related to tornado hazards as well as guide researchers for future studies.

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Appendix 1 – Full Survey

Prior Experience with Tornadoes

First, we’ll ask a few questions about your prior experience with tornadoes. Please know that there are no right or wrong answers to any of these questions. We are only interested in your own experience and opinions.

1. Has a tornado ever hit your home?

    Yes (Skip to Q4)
    No
    Don’t know
    Refused

2. Has a tornado ever hit a building while you were inside?

    Yes (Skip to Q4)
    No
    Don’t know
    Refused

3. Has a tornado ever hit near where you live?

    Yes
    No
    Don’t know
    Refused

Risk Perception

Now, we’d like you to think about the county where you live.

4. How often would you say tornadoes hit ___________ 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
    Don’t know
    Refused

5. If 10 tornadoes hit __________ county in the upcoming years, how many of these would you expect to occur at night when it is dark?

    Response is a number 0-10
    Don’t know
    Refused

6. In which month or months would you say tornadoes are most likely to occur in __________ county?

    9a. [If respondent says a season] Which months do you consider to be [season]?

7. In which month or months would you say tornadoes are least likely to occur in __________ county?

    10a. [If respondent says a season] Which months do you consider to be [season]?

8. Which region of Tennessee do you think is most likely to be hit by a tornado? Would you say West, Middle, or East Tennessee?

    West
    Middle
    East
    All the same (Skip to Q10)
    Don't know
    Refused

9. Which region do you think is least likely to be hit? Would you say West, Middle or East Tennessee?

    West
    Middle
    East
    Don't know
    Refused

10. If a tornado were to hit your area, which direction would the tornado most likely come from? (Interviewer checks one of the following based on response, or completes Other:)

    North
    Northwest
    Northeast
    South
    Southwest
    Southeast
    East
    West
    Other:
    Don't know
    Refused

11. To what extent do you think hills protect nearby places from tornadoes, if at all? Would you say...

    1 = Not at all
    2 = Somewhat
    3 = Very much
    4 = Completely

8 = Don’t know
9 = Refused

12. To what extent do you think bodies of water—such as rivers and lakes—protect nearby places from tornadoes, if at all? Would you say...

    1 = Not at all
    2 = Somewhat
    3 = Very much
    4 = Completely
    8 = Don’t know
    9 = Refused

13. To what extent do you think tall buildings protect cities from tornadoes, if at all? Would you say...

    1 = Not at all
    2 = Somewhat
    3 = Very much
    4 = Completely
    8 = Don’t know
    9 = Refused

Psychological Characteristics

Now, I’ll read a few statements. For each one, please tell me whether you strongly disagree, disagree, agree, or strongly agree.

14. Except in extreme circumstances, my safety is under my control when a tornado threatens.

    1 = Strongly disagree
    2 = Disagree
    3 = Agree
    4 = Strongly agree
    8 = Don’t know
    9 = Refused

15. Surviving a tornado is mostly a matter of luck.

    1 = Strongly disagree
    2 = Disagree
    3 = Agree
    4 = Strongly agree
    8 = Don’t know
    9 = Refused

16. People die when it is their time and not much can be done about it.

    1 = Strongly disagree
    2 = Disagree
    3 = Agree

4 = Strongly agree
8 = Don’t know
9 = Refused

Tornado Watch and Warning Knowledge

Now, we would like to know how people interpret tornado watches and tornado warnings.

17. In your own words, what does a tornado watch mean?

18. In your own words, what does a tornado warning mean?

Tornado Warning Access (Daytime/Nighttime Survey Split)

For the next questions, please think about tornado warnings during the [daytime/nighttime when most people are asleep]. A tornado warning is more immediate than a tornado watch, and means that weather radar shows a tornado may be occurring or a tornado has been spotted in the area.

19. If there was a tornado warning DURING THE DAYTIME, what are the chances you would find out about the warning? Would you say
    0 No chance
    1 Very low
    2 Low
    3 High or
    4 Very high
    8 Don't know
    9 Refused

20. [If responded 1-4 to the previous question] Thinking about tornado warnings that you get during the [daytime/nighttime when most people are asleep], how do you usually receive these? Do you usually receive these by (interviewer asks each one separately with Yes/No/Don’t know/Refused response options):

    a. Television
    b. Local radio station
    c. Cell phone alert
    d. Searching the internet
    e. Social media, for example, Facebook or Twitter
    f. NOAA weather radio
    g. Call, text, or visit from a friend or family member
    h. Tornado siren
    i. Some other way (specify): ______________________

21. If a tornado warning occurred in ___________ county during the [daytime/nighttime after most people are asleep], what would be the best way to make sure you receive the warning? (Open-ended response, recorded by interviewer)

Tornado Warning Perceptions

Now, thinking about tornado warnings, in general…

22. How accurate do you think tornado warnings are in predicting actual tornadoes touching down? Would you say they are...

    1 = Extremely inaccurate
    2 = Somewhat inaccurate
    3 = Somewhat accurate
    4 = Extremely accurate
    8 = Don't know
    9 = Refused

Tornado Watch and Warning Response (Daytime/Nighttime Survey Split)
(Note: 75% of respondents responded to the warning scenario and 25% responded to the watch scenario.)

Now, we are going to describe some scenarios. Please imagine yourself in each scenario and what you might do. Also, please remember that there are no right or wrong answers. We are interested in your own personal thoughts and reactions.

23. Watch response scenario.

    Daytime Version
    You are home on a Saturday afternoon and learn that the National Weather Service has issued a tornado watch for the area where you live. The watch says conditions are favorable for tornadoes until 8 pm. Which if any of the following would you do upon learning about the watch? (Yes/No/Don't know/Refused for each)

    a. Do nothing, continue on as before
    b. Turn on the television or radio to find more information
    c. Search the internet to find more information
    d. Use an app on a smartphone or tablet to find more information
    e. Look or go outside to check the weather yourself
    f. Contact friends or family
    g. Seek shelter in your home
        a. If Yes, where in your home would you go for shelter?
    h. Leave your home
        a. If Yes, where would you go?
    i. Pray for safety
    j. Something else (specify):

    Nighttime Version
    You are home on a Saturday night and learn that the National Weather Service has issued a tornado watch for the area where you live. The watch says conditions are favorable for tornadoes until 5 am. Which if any of the following would you do upon learning about the watch? (Yes/No/Don't know/Refused for each)

    a. Do nothing, continue on as before
    b. Turn on the television or radio to find more information
    c. Search the internet to find more information
    d. Use an app on a smartphone or tablet to find more information
    e. Look or go outside to check the weather yourself
    f. Contact friends or family

g. Seek shelter in your home
    i. If Yes, where in your home would you go for shelter?
h. Leave your home
    i. If Yes, where would you go?
i. Pray for safety
j. Something else (specify):

24. Warning response scenario.

Daytime Version
You are home on a Saturday afternoon and learn the National Weather Service has issued a tornado warning for the area where you live. A tornado warning means that weather radar shows a tornado may be occurring or a tornado has been spotted in the area. Which if any of the following would you do upon learning about the warning? Would you… (Yes/No/Don't know/Refused for each)

a. Do nothing, continue on as before
b. Turn on the television or radio to find more information
c. Search the internet to find more information
d. Use an app on a smartphone or tablet to find more information
e. Look or go outside to check the weather yourself
f. Contact friends or family
g. Seek shelter in your home
    i. If Yes, where in your home would you go for shelter?
h. Leave your home
    i. If Yes, where would you go?
i. Pray for safety
j. Something else (specify):

Nighttime Version
You are home asleep on a Saturday night. You are awakened in the middle of the night and learn that the National Weather Service has issued a tornado warning for the area where you live. A tornado warning means that weather radar shows a tornado may be occurring or a tornado has been spotted in the area. Which if any of the following would you do upon learning about the warning? Would you… (Yes/No/Don't know/Refused for each)

a. Do nothing, go back to sleep
b. Turn on the television or radio to find more information
c. Search the internet to find more information
d. Use an app on a smartphone or tablet to find more information
e. Look or go outside to check the weather yourself
f. Contact friends or family
g. Seek shelter in your home
    i. If Yes, where in your home would you go for shelter?
h. Leave your home
    i. If Yes, where would you go?
i. Pray for safety
j. Something else (specify):

Home/Housing Characteristics

We'd like some information about the type of house you live in.

25. Do you live in a mobile or pre-manufactured home?

    Yes
    No
    Don’t know
    Refused

26. [If yes] Is your home located in a mobile home park?

    Yes
    No
    Don’t know
    Refused

27. [If no to question about mobile/pre-manufactured home] Which of the following best describes your home?

    Detached, single-family house
    Duplex or multi-family house
    Apartment
    Other: _________
    Don’t know
    Refused

28. Does your home have a basement?

    Yes
    No
    Don’t know
    Refused

29. Does your home have a crawl space?

    Yes
    No
    Don’t know
    Refused

30. Is there a specially purchased or built storm shelter on the property where your home sits?

    Yes
    No
    Don’t know
    Refused

31. (For land-line respondents only) Do you have a cell phone?

    Yes
    No

Don't know
Refused

32. Is your cell phone a smartphone?

Yes
No
Don't know
Refused

33. Do you or another member of your household have a private vehicle?

Yes
No
Don't know
Refused

Geographic Characteristics

34. What is your zip code?

______ Enter

35. Would you describe the area where you live as:

Rural
Suburban
Urban
Some other way (specify):
Don't know
Refused

Household and Individual Characteristics

36. Is anyone in your household under the age of 18?

Yes
No
Don't know
Refused

37. Is anyone in your household 65 or older?

Yes
No
Don't know
Refused

38. How many years have you lived in Tennessee?

39. Are languages other than English spoken in the home?

Yes
No
Don't know
Refused

a. If yes, what language is that?
____

Individual Characteristics

40. What is your gender?

Male
Female

41. How old are you?

___ Years (-99 for refused)

42. What race or races do you consider yourself to be? (check all that apply)

1 White, non-Hispanic
2 Hispanic
3 Black
4 American Indian or Alaska Native
5 Asian
6 Native Hawaiian or other Pacific Islander
7 Mixed race (biracial, multiracial)
8 Don't know
9 Refused

43. I'll read a list of education levels. Please stop me when I get to the category that best represents your education level.

1 Less than high school
2 High school graduate
3 Some college, or a technical degree, or an associates degree
4 College graduate or higher
8 Don't know
9 Refused

44. Would you describe your marital status as...

1 Single
2 Separated
3 Divorced
4 Married
5 Living together with a long-term partner
6 Widowed
8 Don't know

9 Refused

45. Are you currently employed?

Yes
No
Don't know
Refused

a. If > 0, do you work a night shift?

Yes
No
Don't know
Refused

46. Household income.

I am going to read you some household income levels. Please stop me when I get to the category that best represents your total household income before taxes in 2015?

□ Less than $20,000	□ $50,000 to less than $60,000	□ $90,000 to less than $100,000
□ $20,000 to less than $30,000	□ $60,000 to less than $70,000	□ $100,000 to less than $110,000
□ $30,000 to less than $40,000	□ $70,000 to less than $80,000	□ $110,000 to less than $120,000
□ $40,000 to less than $50,000	□ $80,000 to less than $90,000	□ $120,000 or greater

Don't know
Refused