Intended Response to Tornado Watches among Tennessee Residents

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ABSTRACT: Tornado watches are issued by the National Weather Service when conditions are favorable for tornado formation. Individuals' responses to a tornado watch may affect their ability to seek shelter before a tornado strikes. Here, survey data of Tennessee residents were used to determine common patterns in intended responses to two tornado watch scenarios: one during daytime, and the other at nighttime. Three common patterns were identified for a daytime watch: doing nothing, seeking information using technology, or seeking shelter and praying for safety. The two patterns for a nighttime watch were either to do nothing or to react actively by seeking further information, seeking shelter, and contacting friends and family. Logistic regressions indicated younger participants, those with prior tornado experience, and those who understood a tornado watch were less likely to intend to seek shelter and pray for safety during the daytime. Older participants and those without strong self-efficacy beliefs were less likely to use technology to find further information. For the nighttime scenario, participants living in east Tennessee and those who believed that bodies of water provide protection from tornadoes were more likely to respond actively, while wealthier participants and those living in single- or multifamily houses were less likely to respond actively. These results show that intended watch response is influenced by many factors, including age, income, and self-efficacy beliefs, as well as knowledge of and experience with tornadoes. In addition, those who do not understand the meaning of a tornado watch may be more likely to seek shelter prematurely.

SIGNIFICANCE STATEMENT: We sought to determine common intended responses to tornado watches, a type of alert that indicates conditions are favorable for tornadoes over the next few hours, among the public. We then analyzed which participant characteristics were associated with these common response types. Age, income, housing type, belief in tornado myths, knowledge of watch terminology, and belief that one's own actions affect tornado survival likelihood were all significantly associated with common response types. These findings are important for forecasters, broadcasters, and others responsible for alerting the public for severe weather. Clarifying tornado watch terminology, dispelling myths, and specifying where those in mobile homes can find shelter are all important strategies for a better-prepared public.

KEYWORDS: Social Science; Societal impacts; Vulnerability

1. Introduction

As meteorological ingredients conducive to severe weather formation are forecast and realized, several products are issued by various bodies within the National Oceanic and Atmospheric Administration (Brotzge and Donner 2013). A *tornado watch* is issued by the Storm Prediction Center several hours before convective initiation is expected. This indicates that conditions are favorable for severe weather formation, including tornadoes. A *tornado warning* is issued by meteorologists at the local National Weather Service (NWS) office when a tornado has been detected by radar or observed by storm spotters, or when tornado formation appears imminent. The main differences between a watch and a warning are timing—watches are valid for several hours, while warnings are valid for an hour or less—and, perhaps most importantly, urgency; tornado watches are usually issued hours before expected tornado formation, while tornado warnings are issued within minutes of formation. As such, the recommended action for a tornado warning—sheltering in an interior location away from windows—would be impractical during a tornado watch. Instead, during a watch the recommended actions are to review one's safety plan and room and to check for supplies (NOAA 2021).

Of these two types of tornado alerts, a much greater proportion of research has been devoted to tornado warnings since a tornado warning represents an imminent threat during which protective action must be undertaken to maintain one's safety. Hazards research has found that individuals tend to undertake a series of actions that may include warning receipt and confirmation, risk personalization, and sheltering (Mileti and Sorensen 1990; Brotzge and Donner 2013; Demuth et al. 2022). There are many modes of tornado warning receipt, including television (Brown et al. 2002; Hammer and Schmidlin 2002; Nunley and Sherman-Morris 2020; Demuth et al. 2022), internet (Nunley and Sherman-Morris 2020), tornado sirens (Liu et al. 1996; Comstock and Mallonee 2005), and cellular telephone alerts (Sherman-Morris 2010; Casteel and Downing 2013; Jauernic and Van Den Broeke 2017; Demuth et al. 2022). Having multiple ways of receiving tornado warnings may help members of the public stay aware during a tornado threat (Ellis et al. 2020).

Actions undertaken after warning receipt vary widely. Individuals may shelter in place, move to a safer location for shelter, or do nothing. Tornado fatality rates are substantially lower for people who do take shelter than for those who do not (Hammer and Schmidlin 2002), particularly

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in violent tornadoes (Paul and Stimers 2012). Previous studies have identified personal characteristics associated with preparedness actions, plans, and intents when a tornado threatens. Individuals from regions where tornadoes are common tend to be more adequately prepared for a tornado (Jauernic and Van Den Broeke 2017; Ripberger et al. 2019). Having graduated high school (Balluz et al. 2000) and being female (Sherman-Morris 2010; Silver and Andrey 2014) make an individual more likely to seek shelter after warning receipt. Alabama residents in households with children were more likely to have participated in a tornado drill, while residents over age 60 were less likely to have done a drill (Chaney et al. 2013). The oldest participants surveyed by Ripberger et al. (2019) were less likely to express confidence that they would receive and respond to a tornado warning than younger participants. Perceived warning accuracy (Ripberger et al. 2014) has been hypothesized to affect public response as well, although a recent study by Lim et al. (2019) found that false alarms have a very limited effect on perceived warning accuracy in the Southeast.

Home type and shelter access are other factors affecting warning response. Mobile home residents are particularly vulnerable to tornadoes (Brooks and Doswell 2002; Simmons and Sutter 2007) and less likely to have a plan for a tornado alert (Chaney and Weaver 2010). They may also believe that their mobile home provides adequate shelter (Ash 2017; Ash et al. 2020) and have a disproportionately longer travel time to a truly safe location (Schmidlin et al. 2009; Strader et al. 2019). Several study participants interviewed by Demuth et al. (2022) indicated a lack of adequate and available shelter during a tornado, limiting their ability to seek protective action.

Several cognitive factors have been associated with shelter-seeking intent or action, such as perceptions of tornado vulnerability and warning accuracy (Blanchard-Boehm and Cook 2004; Walters et al. 2019) and fatalism (Schmidlin et al. 2009; Senkbeil et al. 2012; Walters et al. 2019). The effects of prior tornado experience are less clear. Paul et al. (2015) found that those with prior experience with tornadoes were less likely to take shelter during the 2011 Joplin, Missouri, tornado. On the other hand, case studies by Comstock and Mallonee (2005) and Silver and Andrey (2014) found that warning compliance was higher in communities that were recently hit by a tornado. Individuals who reported prior experience with tornadoes were more likely to understand their own county's climatological risk (Ellis et al. 2018), and residents of Tuscaloosa, Alabama, were likely to change their sheltering plans after the 2011 tornado that hit the city (Senkbeil et al. 2012).

A recent avenue of research has been toward the "warn on forecast" (WoF) paradigm, in which convective hazards such as tornadoes are assessed and forecast for an hour or more in advance, well before the forecast storm starts to produce these hazards (Stensrud et al. 2009, Brotzge and Donner 2013; Stensrud et al. 2013). In addition to the complexity of convection models and observations required for WoF (Stensrud et al. 2013), another challenge has been the anticipated societal response to warning lead times an hour or more in advance. While warning lead times up to 15 min before a tornado are associated with reduced casualties, there is some evidence that casualty rates are actually higher for lead times greater than 15 min (Simmons and Sutter 2008), although the authors of this study noted that this trend is driven by a few high-impact events. Similarly, a survey study by Hoekstra et al. (2011) found that lead times preferred by the public averaged 33.4 min, and participants reported that they would interpret a tornado forecast as less dangerous if given an hour of lead time. Another proposed paradigm, Forecasting a Continuum of Environmental Threats (FACETs), notes the "information void" between the time scales of watches and warnings, during which the public is not routinely updated with new information on forecast hazards that they may need to refine their planned protective action (Rothfusz et al. 2018).

A few studies have specifically involved tornado watches, most of which examined how well the public differentiates between watches and warnings (Liu et al. 1996; Balluz et al. 2000; Schultz et al. 2010; Sherman-Morris 2010; Silver 2015). The rate of correct differentiation between the two alerts varies by study but tends to be well over 50% and even as high as 90% (Schultz et al. 2010). However, while this rate of correct differentiation is relatively high, the tornado watch product in its current form may not be well understood by the general public because of its rigidity in communicating expected tornado severity, risk levels, and recommended safety decisions (Mason and Senkbeil 2015). One example of a tornado watch currently used for situations of elevated risk is called a *particularly dangerous situation* (PDS) tornado watch. PDS tornado watches are rare but have been found to influence decision-making by members of the public (Gutter et al. 2018). Survey participants have indicated that preparation and monitoring were common intended actions when provided with 4–8 h of advanced notice for a possible tornado (Krocak et al. 2019). Beyond these findings, little research exists on public action during tornado watches, which remains an important and understudied avenue of inquiry and the subject of this study. Findings from this study may shed light on what actions are undertaken by the general public upon learning of a tornado watch, which may in turn reveal their perceptions and understanding of these alerts. In addition, precautions undertaken hours before a tornado threatens may affect one's ability to find shelter should a tornado warning be issued later (DeMuth et al. 2022).

In this study, we aim to identify intended actions among members of the public when faced with a tornado watch using survey responses of Tennessee residents. Study results add to the current state of knowledge on public actions undertaken before tornadoes occur that may affect one's likelihood of warning receipt and ultimate survival. While this study is similar to studies on severe weather preparation by Krocak et al. (2019) and tornado warning response by Walters et al. (2019), it is unique in its focus on tornado watch response in the Southeast and its aim to draw connections between sociodemographic and cognitive factors and intended watch response. Study findings allow for easy comparison with established knowledge of public response to tornado warnings and create new insights into public response during the understudied

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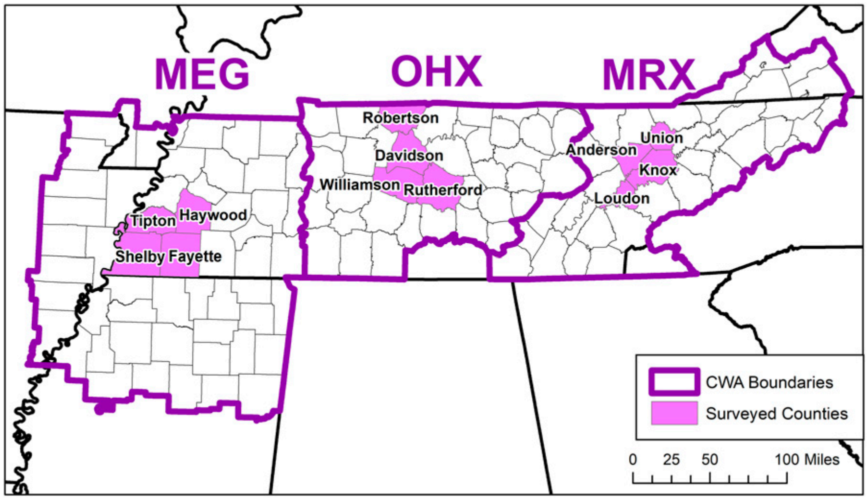

FIG. 1. Counties in Tennessee that were included in the survey used for this study.

time frame beyond the scale of tornado warnings. Our two main research questions were as follow:

1) What patterns of intended behaviors after tornado watch issuance are identifiable, and how can they be grouped into classes?
2) What cognitive and sociodemographic characteristics are associated with membership in each class?

2. Data and methods

a. Study area

Our study area includes 12 counties in Tennessee (Fig. 1). These counties include the three most populous cities in Tennessee—Memphis, Nashville, and Knoxville—as well as surrounding suburban and rural areas. As a part of the southeastern United States, this is an important setting for research on societal aspects of the tornado hazard because of the region's high vulnerability to devastating tornadoes. The lower Mississippi and Tennessee River valley regions exhibit one of the nation's highest tornado fatality rates (Ashley 2007; Fricker et al. 2017). The reasons for this are numerous and complex. One factor is that mobile homes compose a substantial portion of the housing stock in the Southeast (Strader and Ashley 2018), and thus a given tornado has a relatively high likelihood of striking mobile homes. Mobile home residents are at an elevated vulnerability to tornadoes. They tend to overestimate their safety in mobile homes (Ash 2017; Ash et al. 2020), even though they are in fact a dangerous place to be during a tornado (Sutter and Simmons 2010; Strader et al. 2021) because of their structural characteristics and distance from adequate shelters (Schmidlin et al. 2009; Strader et al. 2019).

The timing of tornadoes, including occurrence at night and during the cool season, is another contributor to fatality rates in the Southeast. Nocturnal tornadoes are dangerous because members of the public report being less likely to receive tornado warning messages at night (Mason et al. 2018; Krocak et al. 2021). This leaves them less able to take protective action before a tornado strikes. As a result, fatality rates from nocturnal tornadoes are much higher than daytime tornadoes (Simmons and Sutter 2005). Recently, Strader et al. (2022) found that nocturnal tornadoes produced fatality rates twice as high as daytime tornadoes. Nocturnal tornadoes (Ashley et al. 2008) and the meteorological conditions favorable for their formation (Davies and Fischer 2009; Kis and Straka 2010) are more common in the Southeast than in other tornado-prone regions of the country. Tornadoes occurring between the months of November and February, when day lengths are short, have become more common since the mid-twentieth century (Childs et al. 2018), as has the overall number of tornadoes in the Southeast (Gensini and Brooks 2018). This trend is expected to continue in the future (Gensini and Mote 2015).

Many residents of the Southeast experienced heightened social vulnerability to environmental hazards. This means that those individuals are less able to prepare for, respond and adapt to, or recover from threats such as tornadoes. Wealth, age, race and ethnicity, rurality, and other factors influence one's social vulnerability to climate hazards (Cutter et al. 2003; Emrich and Cutter 2011), including tornadoes (Kashian et al. 2021). The sociodemographic makeup of the Southeast makes it a region of elevated social vulnerability (Borden et al. 2007; Emrich and Cutter 2011), exacerbating the tornado threat for people who live there (Boruff et al. 2003).

b. Survey

For this study, we used data obtained via a survey of 1804 people living in the 12 counties of Tennessee (Fig. 1) that compose our study area. Together, these counties comprise the three largest cities of the state (Nashville, Memphis, and Knoxville) and the suburban and rural areas that surround them. The survey was approved by the University of Tennessee Institutional Review Board and was conducted

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from February to July 2016 over telephone calls to randomly selected telephone numbers. Response rates were 14.1% via landline and 19.7% via cellular telephone. Data obtained from this survey have been used in other studies on tornado hazard understanding and response, including Ellis et al. (2018), Mason et al. (2018), Ellis et al. (2019), and Walters et al. (2019). As shown in these studies, this survey's sample population tended to be older, more likely to identify as female, and more likely to report having college education, relative to the general population of these counties. Participants who gave verbal informed consent to the survey were asked questions about their own sociodemographic characteristics, as well as those in their household; cognitive factors including beliefs and perceptions about tornado threats; and their intended responses to one of several hypothetical scenarios involving tornadoes. Two of these hypothetical tornadoes pertained to a tornado watch issued on a Saturday: one taking place during the afternoon, with the tornado watch valid until 2000 LT, and the other taking place at night, with the tornado watch valid until 0500 LT Sunday. Although the original survey goal was to collect an even number of responses for the daytime and nighttime scenarios, an error in the program used to assign the scenarios to each participant during recruitment resulted in a greater proportion of daytime responses than nighttime responses. The details read to the participant were as follows:

> You are home on a Saturday [afternoon/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 [8 pm/5 am].

Although the Storm Prediction Center issues supplementary information with tornado watches—such as probabilities of tornadoes, wind, and hail—the intended focus of the survey was on participants' intended response to a watch and additional supplementary information was not included so as not to create confusion. After being read the details of the assigned tornado watch scenario, participants were asked which of the following actions they would undertake:

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) Leave your home.
   a) If Yes, where would you go?
8) Pray for safety.
9) Something else (specify).

Participants could also answer "I don't know" or refuse to answer the question. Participants who said they would do nothing could still select other actions they might take. Participants who indicated that they would leave their home upon watch issuance were asked where they would go, and their answers to this question were manually coded into two groups: one for people who indicated they would leave their house to find shelter or a safer location, and another for all other answers, for example, running errands or other locations not chosen specifically for shelter.

Other questions in the survey pertained to participants' age, gender, income, and education. Other factors described where and with whom the participant lived: one's home type, the region of Tennessee in which they lived, whether they lived with a household member under age 18 or over 65, whether they were married or living with a long-term partner, how long they had lived in Tennessee, and whether they had access to a basement or storm shelter. Participants were also asked what (if any) prior experience they had with tornadoes and whether they felt that hills, bodies of water, and tall buildings protected nearby areas from tornadoes. Participants were also read statements pertaining to one's belief in self-efficacy: "Except in extreme circumstances, my safety is under my control when a tornado threatens"; luck: "Surviving a tornado is mostly a matter of luck"; and fatalism: "People die when it is their time and not much can be done about it," and they were asked to evaluate the degree to which they agreed with these statements on a Likert scale.

c. *Analysis*

To answer the first research question, we separated the responses by scenario—daytime and nighttime—and used Gower's distance (Gower 1971) to determine the similarity between participants' answer sets to the nine possible actions above. Gower's distance is a measure of similarity between observations with multiple parameters, such as response sets to our survey. Responses were mainly categorical (e.g., "yes" or "no"), for which Gower's distance uses the Dice coefficient (Dice 1945) to quantify similarity. Although these techniques were developed in the ecology and biometrics fields, they have been used effectively in hazard prediction and vulnerability analysis (Liu et al. 2015; Jiao et al. 2019). Gower's distance and subsequent statistical analysis was performed using R software.

Separating daytime from nighttime survey responses allows for examination of whether intended responses differ by time of day, which is an important consideration because of the elevated fatality rate of nocturnal tornadoes. Since individuals tend to undertake a series of actions when responding to hazard alerts rather than only a single action (Mileti and Sorensen 1990; Brotzge and Donner 2013; Walters et al. 2019), similar response sets were clustered to determine common patterns of intended action using partitioning around medoids (Botyarov and Miller 2022) and silhouette width to optimize the number of clusters. Each cluster thus contained participants with similar intended responses, representing common responses to tornado watch issuance. For the three clusters in the daytime scenario and two clusters in the nighttime scenario, we performed pairwise Wilcoxon tests with Bonferroni corrections (χ^2 tests of independence) to determine the clusters in which participants were significantly more or less likely to intend to perform each action.

To answer the second research question, we performed a series of bivariate statistical tests. Each test used cluster

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membership as the response variable but had various explanatory variables representing participants' sociodemographic characteristics, cognitive factors, and experience with and knowledge of tornadoes. Chi-squared tests of independence determined significant associations between cluster membership and explanatory variables with three or fewer categories. For explanatory variables with four or more ordinal categories, Wilcoxon–Mann–Whitney (WMW) tests were used to determine significant associations with membership in two categories of intended responses in the night samples Kruskal–Wallis (KW) tests were used to determine significant associations with membership three categories of intended responses in the day samples. Explanatory variables exhibited generalized variance inflation factors below 3.0, indicating that multicollinearity did not present an issue.

The p values from these tests indicate the likelihood that associations between cluster membership and corresponding explanatory variables existed through random chance. Explanatory variables producing a p value of 0.30 or lower were used to build a series of multivariate logistic regressions to determine which explanatory variables were most strongly associated with cluster membership, and therefore intended watch response. We used several different combinations of explanatory variables in these models, prioritizing inclusion of explanatory variables with low bivariate p values, and used Akaike information criterion and residual deviance to select the model containing the optimal combination of explanatory models that best fit the data.

3. Results

A majority of participants identified as female, white, and married or living with a long-term partner without anyone under the age of 18 or over age 65 in the household (Table 1). They also tended to live in single- or multifamily households and had a cell phone but did not have access to a basement or shelter. There were a few significant ($\alpha = 0.05$) differences between the daytime and nighttime participants' sociodemographic and cognitive characteristics (Table 1), but the sample populations were mostly similar. Some intended responses differed between the two samples (Table 2), including the day group being more likely to check the weather outside or leave their home, and the night group being more likely to use an "app" or "smartphone."

The optimal number of clusters for analysis was determined by silhouette width. For the daytime scenario participants, silhouette width was maximized with three clusters, and for the nighttime scenario participants, silhouette width was maximized with two clusters. Thus, we proceeded with bivariate analysis and logistic regressions using three daytime clusters and two nighttime clusters. The intended responses for each cluster are shown below in Tables 3 and 4.

Each daytime cluster exhibited unique characteristics in terms of intended response to a hypothetical tornado watch (Table 3). Cluster 1 was the largest of the three clusters and members were significantly ($\alpha = 0.05$) more likely than other clusters to intend to seek shelter in their home and pray for safety upon watch issuance. Participants in cluster 2 were most likely to indicate that they would do nothing and continue on as before after hearing of a watch. They were least likely to indicate that they would seek shelter in their home, contact friends and family, pray for safety, or turn on the television or radio for more information. Cluster 3 was the smallest cluster, but every member of this cluster indicated that they would search the internet and use an app on a smartphone or tablet for more information. Thus, when examining the intended responses of daytime survey participants, three common patterns are apparent: one group reacts strongly, seeking shelter and praying for safety (cluster 1); one group seeks more information through the internet, smartphones, or tablets (cluster 3); and one group is comparatively unreactive (cluster 2). However, it is important to note that some intended actions—such as turning on the television or radio, checking the weather oneself, or praying for safety—were common across all three clusters, with over half of participants in each cluster indicating that they would do so.

The two nighttime clusters also exhibited significant ($\alpha = 0.05$) differences in intended responses (Table 4). A significantly higher proportion of survey participants in cluster 1 indicated that they would undertake nearly all of the actions provided in the survey. A higher proportion of participants in cluster 2 were likely to do nothing and continue on. The two common patterns for participants in the nighttime scenario were to react actively (cluster 1) or to be relatively unreactive (cluster 2). As with the daytime scenario, over half of participants in each cluster indicated that they would turn on the television or radio for more information and pray for safety upon learning of the tornado watch.

Bivariate tests indicated that cluster membership was not independent of some sociodemographic characteristics and cognitive factors included in the survey. Significant ($\alpha = 0.05$) differences between daytime scenario clusters exist for having a household member over age 65, the number of years for which the participant has lived in Tennessee, proper understanding of a tornado watch, beliefs in protection from buildings, and cognitive factors related to efficacy and fatalism (Table 5). These variables were tested for inclusion in a multivariate logistic regression to predict cluster membership. Other variables returned relatively low p values, although not significant at $\alpha = 0.05$, that were also tested for this regression.

The two clusters of participants in the nighttime scenario also exhibited differences in some sociodemographic and cognitive variables (Table 6). Home type and region of Tennessee were significant at the $\alpha = 0.05$ level, with higher proportions of participants in cluster 2 living in single- or multifamily homes and in west or middle Tennessee. Income and beliefs in efficacy and protection from water were significant at $\alpha = 0.10$. As with the daytime clusters, variables with low bivariate p values were tested in a series of multivariate logistic regressions to predict cluster membership.

After testing several combinations of explanatory variables with low bivariate p values (Table 5) in a logistic regression, we selected the regression with the best data fit and minimal deviance and multicollinearity to model daytime cluster membership as a function of sociodemographic and cognitive characteristics.

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TABLE 1. Sample characteristics for participants in the daytime and nighttime scenarios.

Variable	Day (mean or percentage; $n = 444$)	Night (mean or percentage; $n = 202$)	p value of day/night difference (test)
Gender (% female)	64.1	60.2	0.391 (χ^2)
Age (years)	57.1	51.9	<0.01 (WMW)
Race			0.238 (χ^2)
White	79.9	75.4	
Nonwhite	20.1	24.6	
Income (12 intervals of $10,000)	5.67	5.22	0.157 (WMW)
Education			0.842 (χ^2)
High school diploma or less	26.8	28.5	
Some college, technical, or associates degree	35.1	33.0	
College degree or more	38.1	38.5	
Married or living with long-term partner	62.2	57.6	0.310 (χ^2)
Someone under age 18 in household	25.1	26.6	0.745 (χ^2)
Household member over age 65	46.2	37.5	0.049 (χ^2)
Years living in Tennessee	40.3	37.7	0.164 (WMW)
Had smartphone	67.1	75.2	0.036 (χ^2)
Home type			0.192 (χ^2)
Single- or multifamily home	82.0	77.2	
Other home type	18.0	22.8	
Access to basement or storm shelter	23.7	24.9	0.821 (χ^2)
Live in rural area	49.0	39.1	0.028 (χ^2)
Region of Tennessee			0.199 (χ^2)
West	35.0	38.1	
Middle	30.7	34.7	
East	34.3	27.2	
Prior experience with tornadoes			0.734 (χ^2)
Not nearby	35.0	35.7	
Near where I live	52.8	54.3	
Hit home or building	12.2	10.1	
Efficacy			0.175 (WMW)
Strongly agree	20.3	23.4	
Agree	46.7	46.8	
Disagree	21.0	23.9	
Strongly disagree	12.1	6.0	
Luck			0.004 (WMW)
Strongly disagree	21.9	15.6	
Disagree	47.6	43.2	
Agree	23.3	29.6	
Strongly agree	7.2	11.6	
Fatalism			0.042 (WMW)
Strongly disagree	14.3	9.8	
Disagree	35.8	34.0	
Agree	34.7	35.1	
Strongly agree	15.2	21.1	
Tornado watch knowledge	82.7	79.0	0.315 (χ^2)
Belief in protection from hills			0.071 (χ^2)
Not at all	15.9	22.9	
Somewhat	55.3	47.9	
Very much or completely	28.8	29.2	
Belief in protection from water			0.221 (χ^2)
Not at all	57.8	54.4	
Somewhat	34.1	33.2	
Very much or completely	8.1	12.4	
Belief in protection from buildings			0.151 (χ^2)
Not at all	67.0	64.7	
Somewhat	37.2	25.4	
Very much or completely	5.7	10.0	

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TABLE 2. Intended responses to the given tornado watch scenario.

Intended response	Percent in daytime group	Percent in nighttime group	χ^2 p value
Do nothing, continue on as before	46.2	41.6	0.317
Turn on the television or radio to find out more information	93.0	91.6	0.630
Search the internet to find out more information	31.3	36.1	0.262
Use an app on a smartphone or tablet to find out more information	47.3	60.4	0.003
Look or go outside to check the weather yourself	76.1	65.3	0.006
Contact friends or family	76.8	72.8	0.315
Seek shelter in your home	57.4	59.4	0.700
Leave your home			
No	82.7	87.6	0.016
Somewhere specifically for shelter	13.1	5.9	
Anywhere else	4.3	6.4	
Pray for safety	82.0	79.2	0.467

Daytime cluster 2 (unreactive) was used as the reference group to examine which characteristics were associated with membership in clusters 1 and 3.

In the selected regression (Table 7), a participant was more likely ($\alpha = 0.05$) to be in cluster 1 (shelter seeking; praying) if they were older or did not know the meaning of a tornado watch. Participants were less likely to be in cluster 1 if they believed that cities are "somewhat" protected from tornadoes by buildings ($\alpha = 0.05$) or if they reported experience with a tornado hitting their home or building ($\alpha = 0.10$). A participant was more likely to be in cluster 3 (information seeking on internet, smartphones, or tablets) if they responded to the statement, "People die when it is their time and not much can be done about it" with "Agree" rather than "Strongly disagree" ($\alpha = 0.10$). At the $\alpha = 0.05$ level, participants were less likely to be in cluster 3 if they had a household member over age 65 or responded to the efficacy statement ("Except in extreme circumstances, my safety is under my control when a tornado threatens") with a response other than "Strongly agree." At the $\alpha = 0.10$ level, older participants and those who live in a single- or multifamily home were less likely to be classified in cluster 3.

We repeated the process to predict nighttime cluster membership, once again testing different combinations of explanatory variables with relatively low p values in Table 6 with the goal of optimizing model fit, minimizing deviance, and avoiding multicollinearity in explanatory variables. One of the explanatory variables that was strongly correlated with cluster membership in Table 6 was income. However, of the 202 nighttime survey participants who were clustered, 33 (16.3%) did not report their income. This was a much higher rate of missingness than other variables. To account for this, two regressions were created: one including income as an explanatory variable, and the other without income, but with a larger sample size of

TABLE 3. Intended responses by cluster for the daytime scenario. Pairwise Wilcoxon significance ($\alpha = 0.05$) is indicated with plus and minus signs: a cluster with a significantly higher rate than one other cluster is denoted with a single plus sign, significantly higher than both clusters is denoted with two plus signs, etc.

Intended response	Cluster 1 (n = 214)	Cluster 2 (n = 131)	Cluster 3 (n = 99)
Do nothing, continue on as before	29.4	88.5	26.3
	−	+ +	−
Turn on the television or radio to find out more information	97.2	84.7	94.9
	+	− −	+
Search the internet to find out more information	11.7	11.5	100.0
	−	−	+ +
Use an app on a smartphone or tablet to find out more information	29.4	36.6	100.0
	−	−	+ +
Look or go outside to check the weather yourself	78.5	71.8	76.8
Contact friends or family	95.3	36.6	89.9
	+	− −	+
Seek shelter in your home	85.5	11.5	57.6
	+ +	− −	+ −
Leave your home			
No	86.5	76.3	82.8
Somewhere specifically for shelter	5.1	1.5	6.1
Anywhere else	8.4	22.1	11.1
Pray for safety	92.5	65.6	80.8
	+ +	− −	+ −

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TABLE 4. As in Table 3, but for the nighttime scenario.

Intended response	Cluster 1 (n = 139)	Cluster 2 (n = 63)
Do nothing, continue on as before	0.230	0.825
	−	+
Turn on the television or radio to find out more information	0.957	0.825
	+	−
Search the internet to find out more information	0.432	0.206
	+	−
Use an app on a smartphone or tablet to find out more information	0.727	0.333
	+	−
Look or go outside to check the weather yourself	0.741	0.460
	+	−
Contact friends or family	0.914	0.318
	+	−
Seek shelter in your home	0.770	0.206
	+	−
Leave your home		
No	87.8	87.3
Somewhere specifically for shelter	8.6	0.0
Anywhere else	3.6	12.7
Pray for safety	0.842	0.683
	+	−

participants. Cluster 2 (nonreactive) was used as the reference category for both regressions.

Without including income as an explanatory variable, survey participants living in east Tennessee and those who believe that water bodies offer "very much" or "complete" protection from tornadoes to nearby areas are significantly (α = 0.05) more likely to be classified in cluster 1 and react relatively strongly to a tornado watch (Table 8). Those who believe that locations near water bodies are "somewhat" protected from tornadoes are also more likely to be classified in cluster 1, but this is only significant at the α = 0.10 level. Participants living in single- or multifamily homes were also significantly less likely to be classified in cluster 1 (α = 0.10).

Inclusion of income as an explanatory variable decreased the sample size for the regression and affected its coefficients and their corresponding significance (Table 9). None of the explanatory variables were significant at α = 0.05, but three were significant at α = 0.10. As in the nighttime regression that did not include an income variable, participants who lived in east Tennessee or those who believed that locations are "somewhat" protected by nearby water bodies were more likely to be classified in cluster 1. Income was also a significant variable in this regression, with increasing income negatively correlated with cluster-1 membership.

4. Discussion

Since nocturnal tornadoes are common across the Southeast and because fatality rates are higher for these nocturnal tornadoes, examining differences between intended responses in the daytime and nighttime scenario may provide important knowledge on how public preparedness for a tornado varies with time of day. Between the two scenarios, there were three significantly disproportionate differences in intended warning responses (Table 2). First, a higher proportion of participants indicated that they would go outside to check the weather themselves for the daytime scenario, likely because nighttime scenario participants may not have felt that this was a helpful option. Nighttime participants were, however, more likely than their counterparts in the daytime scenario to use a smartphone or tablet app to find more information (Table 2), which may have been for them an alternative to checking the weather oneself after nightfall. This difference may also be attributable to sociodemographic differences between participants in the two scenarios: nighttime participants were significantly younger and more likely to own a smartphone (Table 1) than those in the daytime scenario. Higher proportions of the daytime scenario participants indicated that they would leave the house upon learning of a tornado watch, although many answers were not specific about the purpose of their trips, and their intent may have been for regular activities that they tend to perform on Saturday afternoons. These findings support those of prior quantitative (Walters et al. 2019) and qualitative (DeMuth et al. 2022) survey analyses in that tornado alert responses are contextual and often dependent on environmental cues, technology, and time of day.

Within the three clusters of daytime scenario respondents, cluster 1 was likely to take the most extreme action, its defining characteristics being to pray for safety and seek shelter in their homes (Table 3). Seeking shelter in one's home is an action more suitable for tornado warnings than watches, since watches do not indicate that a tornado is imminent or ongoing. Indeed, correct knowledge of a tornado watch definition was negatively correlated with membership in cluster 1 (Table 7), indicating that those who can correctly identify the implications of an active tornado watch are less likely to undertake actions that are more appropriate for a warning, such as sheltering in place. Those in cluster 1 relied on television or radio for more information instead of an app and were likely to contact friends and family. This is likely related to the age of

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TABLE 5. Characteristics by cluster and bivariate significance for the daytime scenario.

Variable	Cluster 1 (mean or percentage)	Cluster 2 (mean or percentage)	Cluster 3 (mean or percentage)	p value (test)
Gender (% female)	63.1	68.0	61.2	0.527 (χ^2)
Age (years)	58.6	56.4	57.3	0.434 (KW)
Race				0.986 (χ^2)
White	79.6	80.0	80.4	
Nonwhite	20.4	20.0	19.6	
Income (12 intervals of $10,000)	5.5	5.6	6.1	0.366 (KW)
Education				0.453 (χ^2)
High school diploma or less	29.1	23.1	26.5	
Some college, technical, or associates degree	31.9	41.5	33.7	
College degree or more	39.0	35.4	39.8	
Married or living with long-term partner	59.9	61.5	68.0	0.386 (χ^2)
Someone under age 18 in household	20.6	26.0	33.7	0.044 (χ^2)
Someone over age 65 in household	51.4	51.9	27.3	<0.001 (χ^2)
Years living in Tennessee	45.3	38.2	32.5	<0.001 (KW)
Had smartphone	67.0	69.2	66.0	0.859 (χ^2)
Home type				0.062 (χ^2)
Single- or multifamily home	80.0	88.5	77.6	
Mobile home, apartment, condominium, or other	20.0	11.5	22.4	
Access to basement or storm shelter	25.9	27.3	34.0	0.339 (χ^2)
Live in rural area	47.4	53.5	46.3	0.464 (χ^2)
Region of Tennessee				0.102 (χ^2)
West	33.6	37.4	34.7	
Middle	27.1	29.8	39.8	
East	39.3	32.8	25.5	
Prior experience with tornadoes				0.268
Not nearby	38.8	32.8	29.6	
Near where I live	51.4	55.0	53.1	
Hit home or building	9.8	12.2	17.3	
Efficacy				0.004 (KW)
Strongly agree	18.5	14.5	32.0	
Agree	51.2	43.5	41.2	
Disagree	19.0	26.7	17.5	
Strongly disagree	11.4	15.3	9.3	
Luck				0.334 (KW)
Strongly disagree	22.0	19.2	25.3	
Disagree	45.3	50.0	49.5	
Agree	22.4	26.2	21.2	
Strongly agree	10.3	4.6	4.0	
Fatalism				0.021 (KW)
Strongly disagree	13.1	17.8	12.2	
Disagree	31.3	43.4	35.7	
Agree	37.9	26.4	38.8	
Strongly agree	17.8	12.4	13.3	
Tornado watch knowledge	75.8	90.0	87.8	0.001 (χ^2)
Belief in protection from hills				0.211 (χ^2)
Not at all	19.9	12.2	12.2	
Somewhat	51.7	61.1	56.1	
Very much or completely	28.4	26.8	31.6	
Belief in protection from water				0.371 (χ^2)
Not at all	59.6	57.4	54.6	
Somewhat	30.3	37.2	38.1	
Very much or completely	10.1	5.5	7.2	
Belief in protection from buildings				0.048 (χ^2)
Not at all	73.7	64.3	56.6	
Somewhat	21.5	29.5	36.4	
Very much or completely	4.7	6.3	7.1	

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TABLE 6. As in Table 5, but for the nighttime scenario.

Variable	Cluster 1 (mean or percentage)	Cluster 2 (mean or percentage)	p value (test)
Gender (% female)	60.9	58.7	0.895 (χ^2)
Age (years)	51.0	53.9	0.197 (WMW)
Race			0.156 (χ^2)
White	72.1	82.5	
Nonwhite	27.9	17.5	
Income (assessed in 12 intervals of $10,000, numbered 1–12)	4.85	6.12	0.065 (KW)
Education			0.230 (χ^2)
High school diploma or less	32.1	20.6	
Some college, technical, or associates degree	32.1	34.9	
College degree or more	35.8	44.4	
Married or living with long-term partner	57.8	57.1	0.980 (χ^2)
Someone under age 18 in household	25.7	28.6	0.804 (χ^2)
Someone over age 65 in household	36.5	39.7	0.783 (χ^2)
Years living in Tennessee	38.5	36.1	0.440 (WMW)
Had smartphone	75.4	77.4	0.892 (χ^2)
Home type			<0.001 (χ^2)
Single- or multifamily home	73.3	85.5	
Mobile home, apartment, condominium, or other	26.7	14.5	
Access to basement or storm shelter	32.1	27.4	0.617 (χ^2)
Live in rural area	39.4	38.3	0.970 (χ^2)
Region of Tennessee			0.049 (χ^2)
West	36.0	42.9	
Middle	31.7	41.3	
East	32.4	15.9	
Prior experience with tornadoes			0.714 (χ^2)
Not nearby	36.5	33.9	
Near where I live	52.6	58.1	
Hit home or building	19.9	8.1	
Efficacy			0.057 (WMW)
Strongly agree	25.4	19.0	
Agree	50.0	39.7	
Disagree	18.1	36.5	
Strongly disagree	6.5	4.8	
Luck			0.983 (WMW)
Strongly disagree	16.1	14.5	
Disagree	42.3	45.2	
Agree	29.9	29.9	
Strongly agree	11.7	11.3	
Fatalism			0.988 (WMW)
Strongly disagree	10.4	8.3	
Disagree	32.1	38.3	
Agree	37.3	30.0	
Strongly agree	20.1	23.3	
Tornado watch knowledge	81.0	74.6	0.396 (χ^2)
Belief in protection from hills			0.423 (χ^2)
Not at all	19.9	28.3	
Somewhat	48.5	43.3	
Very much or completely	31.6	28.4	
Belief in protection from water			0.054 (χ^2)
Not at all	48.9	66.7	
Somewhat	36.1	26.7	
Very much or completely	15.0	6.7	
Belief in protection from buildings			0.436 (χ^2)
Not at all	62.3	69.8	
Somewhat	26.1	23.8	
Very much or completely	11.5	6.3	

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TABLE 7. Results of a multinomial logistic regression to predict cluster membership for the daytime scenario. Boldface values indicate significance at the $\alpha = 0.05$ level, and italicized values indicate significance at the $\alpha = 0.10$ level.

Explanatory variable	Cluster 1 coef	Cluster 1 std error	Cluster 1 *p* value	Cluster 3 coef	Cluster 3 std error	Cluster 3 *p* value
Intercept	**1.650**	**0.700**	**0.018**	1.327	0.700	0.103
Age (years)	**0.017**	**0.006**	**0.005**	*−0.014*	*0.007*	*0.064*
Household resident(s) over 65	−0.327	0.266	0.220	**−0.828**	**0.323**	**0.010**
Correct knowledge of a tornado watch	**−1.268**	**0.384**	**<0.001**	−0.139	0.475	0.769
Efficacy ("strongly agree" is reference)						
"Agree"	0.319	0.357	0.372	**−0.772**	**0.388**	**0.047**
"Disagree"	−0.246	0.400	0.538	**−1.019**	**0.448**	**0.023**
"Strongly disagree"	−0.316	0.446	0.480	**−1.185**	**0.528**	**0.025**
Fatalism ("strongly disagree" is reference)						
"Disagree"	−0.125	0.377	0.740	0.266	0.454	0.558
"Agree"	0.560	0.394	0.156	*0.799*	*0.473*	*0.091*
"Strongly agree"	0.369	0.462	0.425	0.274	0.587	0.640
Belief in protection by buildings ("none" is reference)						
"Somewhat"	**−0.698**	**0.289**	**0.016**	0.364	0.319	0.254
"Very much/completely"	−0.729	0.572	0.202	0.400	0.609	0.511
Household resident(s) under 18	−0.364	0.307	0.236	−0.086	0.343	0.802
Single- or multifamily home	−0.486	0.344	0.158	*−0.704*	*0.390*	*0.071*
Prior experience with a tornado ("not nearby" is reference)						
Nearby	−0.237	0.269	0.379	0.047	0.328	0.885
Hit home or building	*−0.828*	*0.427*	*0.053*	0.398	0.465	0.382

cluster-1 members; older participants were significantly more likely to be in cluster 1 (Table 7), and cluster-1 members were older, on average, than the other members of the other two clusters (Table 5). Older participants in Ripberger et al. (2019) expressed less confidence in their ability to receive a tornado warning, so perhaps cluster-1 members in the present study indicated a proactive response to watch issuance because of concern around warning receipt. Having multiple channels through which to receive a warning is an important element of awareness prior to a tornado event (Ellis et al. 2020). While sheltering during a watch may be unnecessary, those who seek out potential warning receipt channels—such as television, radio, or friends and family—proactively modify their situation in a manner that makes them safer, overcoming common inhibitions to warning access (Walters et al. 2020). This may explain why 75% of cluster-1 members demonstrated a correct understanding of a tornado watch (Table 5).

Prior research has found mixed results on how tornado experience affects tornado preparedness and response (Comstock and Mallonee 2005; Senkbeil et al. 2012; Silver and Andrey 2014; Paul et al. 2015; Schumann et al. 2017; Ellis et al. 2018). In the present study, a participant having experienced a tornado hitting their home or building made them significantly less likely to be classified in cluster 1 (Table 7), albeit at a lower significance level ($\alpha = 0.10$) than aforementioned variables. This could indicate that past tornado experience is associated with a better understanding of tornado risk, in terms of both watch response and climatological perceptions

TABLE 8. Results of a binomial logistic regression to predict cluster membership in the nighttime scenario, with income not included. Boldface values indicate significance at the $\alpha = 0.05$ level, and italicized values indicate significance at the $\alpha = 0.10$ level.

Explanatory variable	Cluster 1 coef	Cluster 1 std error	Cluster 1 *p* value
Intercept	0.878	0.569	0.123
Single- or multifamily home	*−0.800*	*0.446*	*0.073*
Region of Tennessee (west is reference)			
Middle	−0.016	0.383	0.966
East	**0.926**	**0.462**	**0.045**
Belief in protection by water ("none" is reference)			
"Somewhat"	*0.619*	*0.373*	*0.098*
"Very much/completely"	**1.234**	**0.611**	**0.044**
Efficacy ("strongly agree" is reference)			
"Agree"	0.005	0.437	0.991
"Disagree"	−0.682	0.483	0.158
"Strongly disagree"	0.495	0.777	0.524
Race (nonwhite)	0.630	0.429	0.142

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TABLE 9. As in Table 8, but with the inclusion of income as an explanatory variable.

Explanatory variable	Cluster 1 coef	Cluster 1 std error	Cluster 1 p value
Intercept	**1.513**	**0.648**	**0.020**
Single- or multifamily home	−0.659	0.499	0.187
Region of Tennessee (west is reference)			
Middle	0.387	0.440	0.379
East	*0.871*	*0.498*	*0.081*
Belief in protection by water ("none" is reference)			
"Somewhat"	*0.804*	*0.419*	*0.055*
"Very much/completely"	0.527	0.654	0.421
Efficacy ("strongly agree" is reference)			
"Agree"	−0.369	0.490	0.452
"Disagree"	−0.769	0.560	0.170
"Strongly disagree"	0.058	0.806	0.943
Race (nonwhite)	0.337	0.467	0.470
Income (assessed in 12 intervals of $10,000, numbered 1–12)	*−0.090*	*0.051*	*0.079*

(Ellis et al. 2018), or with a lack of response to future tornado watches or warnings (Paul et al. 2015). Future studies could further elucidate the relationships among past tornado experience, risk perception, and alert response.

Cluster-1 membership was negatively correlated with the belief that urban areas are "somewhat" protected from tornadoes by tall buildings. This was the only significant relationship with daytime cluster membership and perceptions of tornado protection from land surface features, as explored in Ellis et al. (2019). However, Walters et al. (2019) found that a similar perception of tornado protection by water bodies made survey respondents less likely to use technology to seek information during a daytime tornado warning and less likely to be nonreactive during a nocturnal tornado warning. Our finding on perceived building protection making one less likely to take actions that include shelter-seeking and prayer does not match thematically with those in Walters et al. (2019), in which similarly misguided perceptions make one less likely to use technology or be nonreactive, nor is there a similar significant effect in this study for those who believe urban areas are "very much" or "completely" protected by buildings (Table 7). Thus, the significant coefficient for the "somewhat" protection level may be due to random chance, but additional research on how public misconceptions about tornadoes affect response to alerts would be necessary to confirm or refute this.

A notable feature of cluster 3 in the daytime scenario was that 100% of the members indicated they would use the internet and an app (Table 3), which is likely related to the relatively young age of this cluster's members or those in their household; younger participants or those who had a household member over age 65 or were less likely to be categorized in cluster 3 than in cluster 2 (Table 7). Technology usage is common among young people when a tornado warning is issued (Sherman-Morris 2010; Jauernic and Van Den Broeke 2017), and these results suggest that the same pattern is true for watches. Participants living in a single- or multifamily home were also less likely to be classified in cluster 3 relative to cluster 2. This result indicates that individuals living in this kind of housing stock are less likely to seek information upon learning of a tornado watch relative to those living in mobile homes or apartments, which are inadequate for sheltering (Sutter and Simmons 2010). This suggests that those living in single- or multifamily houses may exhibit a confidence—or at least lack of concern—in having a safe shelter available if a tornado were to strike. Information seeking behavior and visual interpretation of hazard information are important aspects of warning response (Schumann et al. 2017). Future studies could examine the relationship between tornado watch response and subsequent warning response in light of these findings.

Cluster-2 members were more likely to express disbelief in one's own control during a tornado event, which is not surprising because participants in cluster 2 were most likely to do nothing upon hearing of a tornado watch and continue on as before. Walters et al. (2019) found a similar pattern in those who had a strong sense of fatalism—"people die when it is their time and not much can be done about it"—and reacted passively to tornado warnings. While it is important to note that we included responses to this same fatalism statement in our analysis and did not find significant results on it, the themes of the findings match: cognitive factors do play a role in determining one's response to tornado alerts. However, as Demuth et al. (2022) note, one's sense of efficacy when a tornado threatens is often limited by situational factors beyond their control: individuals may want to keep themselves safe but feel unable to because of their own personal circumstances. While survey respondents in Demuth et al. (2022) were interviewed shortly after a devastating tornado instead of surveyed about a hypothetical watch, it is possible that our participants did not anticipate having sufficient options to mitigate their own risk.

There were two clusters of intended responses for the nighttime scenario: one cluster 1) that was significantly more likely to intend to take nearly all response actions, and another 2) that continued on as before. The results of the regressions determining cluster membership depended on whether income was included as an explanatory variable. In the regression without income, participants living in east Tennessee and those who believed in protection from water were more likely

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to be in cluster 1 and respond more actively to a nighttime tornado watch. This finding may indicate that a lack of familiarity with tornadoes is associated with an active reaction to tornado watches: lakes and rivers in fact do little to inhibit tornadoes, and east Tennessee is climatologically the least active region of the three for tornadoes (Brown et al. 2016). Krocak et al. (2019) found that people living in inactive tornado regions expressed uncertainty in what they would do when given 4 h of notice before a future severe weather event, a time scale similar to that of a tornado watch. However, other factors in this study such as knowledge of a tornado watch and prior experience with tornadoes did not exhibit significant disproportionality between the two clusters (Table 5). Participants living in single- or multifamily houses were less likely to be categorized in cluster 1 (Table 8), consistent with the results of the daytime cluster regression in that those who live in this kind of housing stock are less likely to react actively to a tornado watch (Table 7).

When income is introduced to the regression as an explanatory variable, the sample size is reduced because missingness was relatively high. Fewer variables yield significant coefficients: income, living in east Tennessee, and belief that bodies of water are "somewhat" protective are the only three. The signs and resulting interpretations of the east Tennessee and water body variables are unchanged from the regression without income: these participants were more likely to be classified in cluster 1, indicating an active response to a nighttime tornado watch. Income, measured in increments of $10,000, was negatively associated with cluster-1 membership, indicating that wealthier participants were less likely to react strongly to a nighttime watch.

5. Conclusions

In this study, we examined intended responses to issuance of tornado watches among members of the public in Tennessee. We used Gower's distance, partitioning around medoids, and silhouette width to identify three common patterns of intended response for a daytime watch, and two patterns of intended response for a nighttime watch. Then, we used logistic regressions to determine sociodemographic and cognitive characteristics associated with these patterns of intended watch response.

The three common patterns in intended response for a daytime watch were to do nothing and continue on as before; to seek more information on smartphones, tablets, and the internet; and to pray for safety and seek shelter. While there were a number of significant associations, younger participants, those reporting prior experience with a tornado, and those with a correct knowledge of a tornado watch were less likely to seek shelter and pray for safety for a tornado watch, while increased age and weak beliefs of self-efficacy made them less likely to use technology to seek further information.

The two common patterns in intended response for a nighttime watch were to do nothing and continue on as before, or to react actively by contacting friends and family, seeking shelter, using apps to find more information, and other actions. Participants living in east Tennessee and those who believed that bodies of water offer protection from tornadoes were more likely to react actively, while those who lived in single- or multifamily homes were less likely to do so only when not taking participant income into account. When including income, wealthier participants were less likely to react actively to a nighttime tornado watch.

These results show that, while sociodemographic characteristics such as age and income play a predictive role in determining intended watch response, psychological beliefs, knowledge of tornado alerts, and past experience with tornadoes do as well. While previous studies have found that most members of the public can correctly differentiate between watches and warnings, further public education efforts on the different types of tornado alerts may aid in preventing future confusion and inappropriate reactions to these alerts. In addition, emphasizing that one's actions before and during a tornado event can affect survival likelihood may prevent apathetic responses to future tornado events.

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Data availability statement. The authors support the commitment made by the American Meteorological Society to open and reproducible research. However, survey data used in this study are securely stored on University of Tennessee servers and are only accessible to approved members of the research team, in accordance with University of Tennessee Institutional Review Board policies.

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