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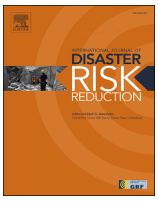

Factors that influenced preferences regarding use of public and private tornado shelters during the COVID-19 pandemic in 2020

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ABSTRACT

This study examines factors shaping individuals' preferences for use of tornado shelters in public and private facilities during the COVID-19 pandemic, utilizing over 6000 surveys collected in Spring and Summer 2020 across the central and eastern United States. We employed Random Forest (RF) ensemble modeling to assess respondents' inclination to use storm shelters in group settings, including a scenario where face masks were mandated at public shelters to reduce COVID-19 exposure. Key findings suggest that both generalized infectious disease risk perception and COVID-19 risk perception consistently ranked as the most influential factors affecting respondents' preferences regarding group tornado sheltering during the pandemic, reflecting the impact of infectious disease concerns. Previous experience with using public tornado shelters was a better predictor of sheltering preferences than cognitive and affective tornado risk perceptions. Tornado risk perception and housing type were less important than the COVID-19 and infectious disease variables. When a hypothetical mask requirement was introduced, individuals with greater COVID-19-related fears showed a heightened inclination to use public storm shelters, suggesting masks influenced sheltering decisions while partially mitigating concerns about enclosed spaces. Residents of mobile homes exhibited stronger preferences for using storm shelters in group settings, underscoring their perceptions of vulnerability to tornadoes. This research emphasizes the substantial role of COVID-19 risk perception in shaping public tornado shelter preferences during the early stages of the pandemic. It also highlights the importance of considering infectious disease risk perception in understanding sheltering behaviors, even outside of a pandemic context.

1. Introduction

Tornadoes can occur during any month in the central and eastern United States (US) but typically reach their greatest frequencies in meteorological Spring from March to June [1], with land-falling tropical systems bringing additional tornado threats in southern and eastern coastal regions during the Summer from June to September [2]. Typically, many residents in these tornado-prone regions minimize their potential exposure to tornadic winds and debris by taking shelter in a variety of group arrangements such as public

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tornadic shelters, storm shelters owned by family members or acquaintances, and/or well-built homes with basements or well-protected central rooms [3–5].

However, in the US such gatherings of people in confined spaces were strongly discouraged or restricted after March 2020 due to the COVID-19 pandemic [6]. The World Health Organization (WHO) declared the COVID-19 pandemic on March 11, 2020, and by the end of March 2020, more than 118,000 cases and over 4200 fatalities had occurred globally (World Health Organization, 2020). The coincidence of the height of the first wave of the COVID-19 crisis with Spring tornado season and Summer hurricane season raised the potential for difficult choices and confusion about which hazard people would place greater emphasis on for sheltering and safety behaviors [7]. This conundrum was most difficult in households where both COVID-19 and tornadoes were believed to be particularly dangerous. For example, in the tornado context, persons living in mobile or manufactured housing (MMH) are recommended to leave their homes and travel to a specially designed tornado shelter or to a sturdier building to reduce the likelihood of injury or death [8,9]. Likewise, persons who are immunocompromised may avoid social situations in which likelihood of exposure to infectious diseases is increased [10].

Thus, the goal of this research was to generate new knowledge about how people perceived danger differently for hazards that occurred simultaneously and for which the recommended actions for each hazard were likely to be in conflict. More specifically, our objective was to understand the relationship between risk and vulnerability beliefs related to tornadoes and to COVID-19, including how beliefs about COVID-19 might have influenced household sheltering plans for tornadoes during the Spring and Summer of 2020. We therefore posed the following research questions.

- What effect did risk perceptions related to COVID-19, infectious diseases, and tornadoes have on respondent preferences for sheltering from tornado threats in group settings during the COVID-19 pandemic in 2020?
- How did having access to one's own tornado shelter or having recent prior experiences with sheltering in group settings influence preferences for sheltering from tornado threats in group settings during the COVID-19 pandemic in 2020?
- Would a face mask requirement at public storm shelters have made a difference in respondents' stated preferences for using these shelters during tornado threats in 2020?
- How did factors such as housing type, geographic location, political affiliation, and other household characteristics influence people's preferences to shelter from tornado threats in group settings during the COVID-19 pandemic in the Spring and Summer of 2020?

2. Research background

The theoretical foundations for this research stem from the concept of vulnerability, in which negative impacts from hazards occur as a function of three components: exposure, susceptibility, and coping or adaptive capacity [11,12]. Exposure captures the extent to which people experience dangerous conditions associated with a hazard, while susceptibility represents attributes or behaviors that exacerbate or alleviate negative consequences given similar levels of exposure. Coping and/or adaptive capacities encompass the ways that people counteract hazard exposure and susceptibility in both short- and long-term contexts to lessen the likelihood and severity of negative consequences. Past research on hazard vulnerability identified demographic and socioeconomic characteristics that were often associated with more negative outcomes during and after disasters (e.g., Emrich and Cutter 2011; [13,14]). For example, households with incomes near or below the poverty threshold [15], or persons experiencing physical and/or mental health challenges, might be more likely to suffer harm in a disaster [16]. In the tornado context, it is well established that persons living in housing that is more easily damaged by winds and debris are more frequently injured or killed; hence, MMHs are of particular importance for efforts to reduce impacts of tornadoes in the US [4,8,9,17].

While previous research examined some aspects of typical tornado shelter use (prior to COVID-19), statistics on rates and demographics of people who have used tornado shelters are rare in the literature. Croskery [18] explored how often public shelters are used by analyzing survey responses in a sample that was national in scope but focused on their Deep South region (AL, AR, FL panhandle, GA, LA, MS, TN, and eastern TX) in the US and found that public shelters are sparsely available. Approximately 78 % of respondents indicated they never use the public shelters, while only 3 % use them regularly. MMH residents indicated higher rates of shelter use, but still only at a rate of 50 %. Schmidlin et al. [3] found from that 30 % of mobile home residents surveyed in Georgia, Mississippi, Oklahoma, and Illinois ever went to a tornado shelter. Stokes and Senkbeil [19] examined factors influencing survey respondents to seek shelter during the 2011 Tuscaloosa, AL tornado and reported only 9 of 100 participants sought shelter in a tornado shelter. Ash [20] found that only 12 % of survey participants in South Carolina had access to a tornado shelter within 100 yards of their home, and about 24 % indicated they had access to a specially constructed tornado shelter within five miles of their home. Ash [20] also reported that factors such as sheltering destination, travel time to the destination, previous sheltering experience, having a sheltering plan, tornado risk perception, race, gender, age, housing tenure, and presence of children in the home as being influential in logistic regression models of tornado sheltering intentions.

It was well established by April 2020 that persons of advanced age (often defined as 65+) and persons with pre-existing medical conditions related to the respiratory, pulmonary, cardiovascular, and/or immune systems were more likely to suffer hospitalization or death because of COVID-19 [21]. Yet, people do not suffer the worst consequences from hazards or diseases merely because of their exposure and susceptibility. It is crucial to also understand how people avoid or lessen negative outcomes in dynamic situations by drawing upon their resource and information networks as well as their own sense of agency and efficacy [22,23]. Thus, in this study we were interested to identify how risk perceptions related to tornadoes and COVID-19 interacted during the Spring and Summer of 2020 to influence people's beliefs about their vulnerabilities to both hazards.

We also wanted to better understand how risk and vulnerability perceptions influenced beliefs about efficacy of recommended protective actions and decision making for protective behaviors such as sheltering in a public tornado shelter, or in group sheltering situations at private residences. We investigated stated preferences of following recommended protective actions when the actions of two hazards are in conflict [24,25]. For example, during Hurricane Harvey in 2017 there were simultaneous flash flood and tornado warnings (i.e., TORFF events) in effect on multiple occasions; it was a challenge for emergency communication how to clarify whether residents should have prioritized protective behaviors for the wind or the flood hazards [26]. Protective action for tornadoes involves being below ground if possible, or being very low to the ground, whereas protective action for flooding involves moving to upper floors of buildings, if possible.

In a similar way, sheltering for tornadoes often involves huddling in small sheltering areas with several other people, particularly if utilizing a public tornado shelter. However, mitigation of exposure to COVID-19 required physical distancing which could have discouraged people from using shared public or private tornado sheltering areas during the Spring and Summer months in 2020 when tornado season, hurricane season, and the COVID-19 pandemic coincided as threats to public health. While several recent works addressed hurricane evacuation during COVID-19 (e.g., Ref. [27–30]), we focused on the tornado context.

Only one previous study focused on tornado sheltering during COVID-19 [7]. In their study, Croskery and colleagues collected over 1000 surveys across the US from May to July in 2020, with half of the responses concentrated geographically in their Deep South region (defined as AL, AR, FL panhandle, GA, LA, MS, TN, and eastern TX). They found that respondents who expressed greater concern about tornadoes also expressed greater concern about COVID-19. Their study also suggested that respondents were less likely to use a public storm shelter given the existing threat of COVID-19. However, the results also indicated that implementation of proper mitigation actions to limit disease spread would increase participants' likelihood of using a public storm shelter.

Our study is similar but adds to the Croskery et al. [7] study in several ways. They fielded the survey from late May to early July 2020 with a sample size of 1180 participants. We fielded the survey twice, once in Spring (14–28 May) and again in Summer 2020 (13 July to 6 August), with a sample size of about 3000 for each period. Thus, our results were generated from a larger sample and over two collection periods. The two sampling strategies were also different, though complementary. Croskery et al. [7] focused geographically on their Deep South region (about half of their respondents), with surveys also collected across much of the tornado-prone eastern two-thirds of the US. Our study covered a similar geographical footprint but was concentrated based on housing type, with about half of participants who indicated they lived in MMHs (more details provided in the next section below). In contrast, Croskery et al. [7] reported about 7.5 % of participants lived in MMHs. In terms of analyses, our study included both cognitive and affective risk perception survey items, and we expanded beyond tornadoes and COVID-19 to ask questions about risk perceptions for infectious diseases more generally. Also, our study is focused on investigating the importance of the independent variables for prediction of group sheltering preferences for *both public and private* sheltering options.

3. Data and methods

3.1. Survey data

In pursuit of the research questions, we deployed an online survey during two separate data collection periods during the Spring and Summer 2020. As COVID-19 became a national health crisis and the number of cases in many locations rose sharply in March and April 2020 [31], we developed the questions for the survey and obtained approval from the University of Florida Institutional Research Board to conduct the research (IRB202000997). During the period 14–28 May 2020, we deployed the survey online via Qualtrics and recruited participants from Qualtrics' pool of potential respondents. The participants were drawn from 20 states in the central and eastern US, where tornadoes often occur during mid-to late Spring (Fig. 1). Because we wanted to include a large sample of participants who might have needed shelter elsewhere due to tornado threats, we placed a question at the beginning of the survey

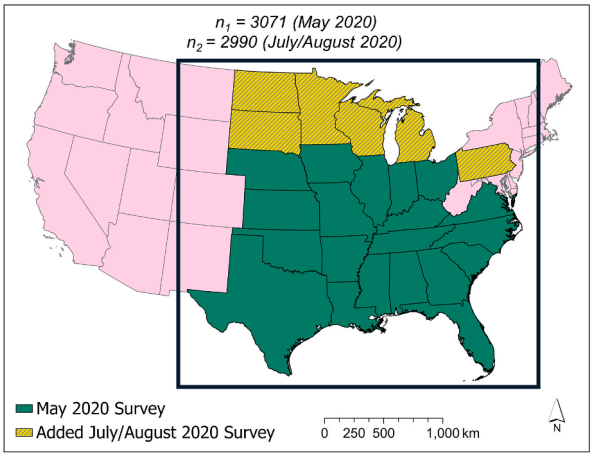

Fig. 1. States included in both data collection periods during May 2020 (denoted by green color), and during July/August 2020 (denoted by yellow hatched pattern).

to filter by housing type and stipulated that approximately half of the completed surveys be from participants who self-reported to be living in MMHs.

The first survey resulted in 3071 complete responses, including 1549 responses from participants living in MMHs (50.4 %). The second survey was completed via Qualtrics from 13 July to August 6, 2020. The second survey data collection netted 2990 complete responses, with 49.6 % of responses from persons reporting living in MMHs. We expanded the study area farther north to encompass additional states that experience tornadoes in July and August. Thus, 26 states were included in the second data collection period (Fig. 1). For both data collection periods, there was a heavy concentration of responses from urban areas. Due to the stipulation on the percentage of respondents living in MMHs, the geographical distribution of the sample was slightly skewed toward a few southeastern states, such that Georgia, North Carolina, and South Carolina, and Alabama were weighted more heavily. The states of Florida, Michigan, Pennsylvania, and Minnesota were slightly underrepresented in the sample. In total, the dataset consisted of 6061 observations, with the greatest number from Texas (824) and the fewest from North Dakota (6) and South Dakota (7).

There were 70 questions in the survey, and the questions were organized in eight primary sections, in the following order: Tornado Risk Perception; Beliefs about Home Ability to Resist Tornado Damage; Availability of and Experience with Tornado Shelters; Perceived Vulnerability to Infectious Diseases; COVID-19 Risk Perception; Tornado Sheltering During COVID-19; Household and Respondent Characteristics. The questions were based on previous research related to risk perception and sheltering behaviors related to wind hazards and infectious diseases [9,32–34]. From the 70 survey items, we derived 28 variables for use in statistical analyses (Table 1). Full wordings of all questions upon which these variables were based are provided in an appendix (Appendix 1). The dependent variables (y1–y4) asked respondents about their potential use of designated public tornado shelters, tornado shelters at private residences, and sheltering within a sturdier home. As the prevalence and types of buildings used as public tornado shelters varies geographically across the US, interpretation of what qualified as a designated public tornado shelter was up to each respondent. Likewise, there are different variations of private tornado shelters (below ground shelters, safe rooms, etc.) and interpretation was again up to the respondents. A de-identified version of the survey data was published via the DesignSafe data depot and is publicly available [35].

Table 1
Variables derived from survey questions and used in this study. Variables that begin with an 'y' denote dependent variables, whereas variables that begin with an 'X' denote independent variables.

Survey Time Period	Variable Short Name	Measurement Level	Variable Indicators
Tornado Sheltering During COVID-19			
Spring & Summer	*Prefer Public Shelter Despite COVID-19*	Ordinal 7	y1
Spring & Summer	*More Likely Public Shelter If Mask Required*	Ordinal 7	y2
Spring & Summer	*Prefer Friend Sturdy Home Tornado Despite COVID*	Ordinal 7	y3
Spring & Summer	*Prefer Friend Private Shelter Tornado Despite COVID*	Ordinal 7	y4
Tornado Risk Perception			
Spring & Summer	*Tornado Risk Perception*	Ratio (Avg of 3 items)	X1
Spring & Summer	*Tornado Negative Affect*	Ratio (Avg of 3 items)	X2
Generalized Infectious Disease Risk Perception			
Spring & Summer	*Perceived Disease Infectibility*	Ratio (Avg of 4 items)	X3
Spring & Summer	*Perceived Disease Resistance*	Ratio (Avg of 3 items)	X4
COVID-19 Risk Perception			
Spring & Summer	*COVID-19 Risk Perception*	Ratio (Avg of 3 items)	X5
Spring & Summer	*COVID-19 Negative Affect*	Ratio (Avg of 3 items)	X6
Housing Type			
Spring & Summer	*Manufactured Home*	Binary	X7
Spring & Summer	*Single-Family House*	Binary	X8
Spring & Summer	*Mobile Homes RVs Tiny Homes*	Binary	X9
Household and Respondent Characteristics			
Spring & Summer	*Republican*	Binary	X10
Spring & Summer	*Democrat*	Binary	X11
Spring & Summer	*NWS Southern Region*	Binary	X12
Spring & Summer	*NWS Eastern Region*	Binary	X13
Spring & Summer	*Children Under 18*	Binary	X14
Spring & Summer	*Adults 65 or Older*	Binary	X15
Spring & Summer	*Black or African American*	Binary	X16
Spring & Summer	*Male Gender*	Binary	X17
County Level COVID-19 Case Data			
Summer	*Percent All Cases New Jun Aug 2020* (models M1A, M2A, M3A, M4A)	Ratio	X18
Spring	*Percent All Cases New Apr May 2020* (models M1, M2, M3, M4)	Ratio	X19
Availability of and Experience with Tornado Shelters			
Spring & Summer	*Have Underground Shelter*	Binary	X20
Spring & Summer	*Have Above Ground Shelter*	Binary	X21
Spring & Summer	*Frequency Go Public Shelter Since 2018*	Ordinal 5	X22
Spring & Summer	*Frequency Go Friend Shelter Since 2018*	Ordinal 5	X23
Spring & Summer	*Frequency Go Friend Home Shelter Since 2018*	Ordinal 5	X24

3.2. Random Forests models

The use of Random Forests (RF) is comparatively new in the field of hazard risk perception. RF is an ensemble of decision trees (forest) where random refers to the random sampling from the original data and random variable sets drawn to build multiple trees [36]. Although linear and logistic regression models are more commonly used, we adopted RF classification because it performs better than other regression and classification models in terms of avoiding overfit or underfit to the input data, and it is robust to outliers [37,38]. We also used RF classification because we wanted to identify the most important variables in tornado sheltering decision making, which is another strength of RF ensemble models [36]. Furthermore, most of our variables were measured using an ordinal or categorical scale (e.g., Likert scale 1–7, with neutral mid-point; Table 1). Thus, RF classification was appropriate to analyze these data types [39].

In this study, we used the *randomForest* R package [40] to conduct analyses. We used two metrics provided as outputs of RF models, Mean Decrease in Accuracy (MDA) and Mean Decrease in Gini Impurity (MDG), to rank variable importance [41]. MDA measures the reduction in accuracy of the model when a particular feature is removed or shuffled randomly. The larger the value of MDA, the greater importance of the variable. Specifically, MDA is calculated by first computing the model's accuracy with all features intact (out-of-bag accuracy). The feature of interest is then permuted, and the accuracy is recalculated. MDA represents the average difference in these accuracies, providing an estimate of the feature's importance for accurate prediction. MDG is the overall average of the sum of the weighted decreases in impurity across all node splits for a variable [42]. Researchers may examine both metrics [41,43], however MDA is the superior importance measure [42]. These two indices provide complementary information though they are based on different metrics; thus, interpretation of variable importance will vary between them [41].

3.3. Tuning hyperparameters

Regression and decision tree model outputs are sensitive to nonrepresentative samples, outlier observations, and to data types of input variables, resulting in models that accurately predict the input data but may not generalize well to another data set. However, RF models allow tuning of model hyperparameters to reduce likelihood of overfitting. The major tuning hyperparameters were number of trees (*ntree*), depths of trees, and number of random variables tried in each tree. We used a grid search approach and evaluated area under the curve (AUC) to explore how many trees to use in the forest [44,45]. We ran the models using *ntree* = 500, 1,000, and 2,000, and found that AUC remained stable from 1000 to 2000 trees. On this basis, we used *ntree* = 1000. The node size function in the RF package allows users to control the minimum number of data points for each node and therefore controls the depths of trees. Larger values of node size prevent growth of each tree, which reduces processing time but hinders the natural growth of trees increasing the propensity to misfit models. Therefore, we kept node size small (*nodesize* = *1*, which was the default) to allow for deeper tree growth and more robust model results. For the dependent variables, we used four and six random variables, respectively. We used the *mtry* function to find the optimal value to guard against misfitting of the models [45]. We used the *tuneRF* function and specified the key settings of *stepFactor* = 1.5 and *improve* = 0.01 [40]. For the dependent variables, we found the out-of-bag error rate was lowest for the following values*:* *mtry* = 4 for M1 and M1A, *mtry* = 6 for M2 and M2A, *mtry* = 5 for M3, *mtry* = 7 for M3A, *mtry* = 5 for M4, and *mtry* = 10 for M4A. Finally, we used the function *importance* to identify the most important variables [44,45].

We ran a total of eight models comprised of the four dependent variables and using two survey time periods: May (Spring) and July/August (Summer) of 2020 (Table 2). Each model was comprised of 24 independent variables (Table 1). We were most interested in identifying which factors were more influential for people who expressed greater likelihood to leave home and take shelter in a public or private storm shelter, or in a sturdier home, during tornado threats, despite the risk of exposure to COVID-19. The independent variables represented six concepts that we hypothesized could be influential for tornado sheltering intentions during COVID-19 (Table 1): Tornado Risk Perception, Availability of and Experience with Tornado Shelters, Generalized Infectious Disease Risk Perception, COVID-19 Risk Perception, Housing Type, Household and Respondent Characteristics, and County Level COVID-19 Case Data.

4. Results

4.1. Summary statistics for independent variables related to Tornado sheltering

There is little existing data on the prevalence of private tornado shelters in the US. Thus, our results provided some fundamental data of use to interested research and operational communities. In terms of household access to a specially constructed tornado shelter on their property, approximately 20 % (Spring survey) and 18 % (Summer survey) of respondents indicated that they had an underground tornado shelter on their property (X20). The percentages were slightly lower for those who indicated they had an above

Table 2
Model matrix for analyses.

Model Name	Dependent Variable	Survey Time Period
Model 1 (M1)	*y1: Prefer to use Public Storm Shelter Despite COVID-19*	Spring 2020
Model 1A (M1A)		Summer 2020
Model 2 (M2)	*y2: More Likely to use Public Shelter If Mask Required*	Spring 2020
Model 2A (M2A)		Summer 2020
Model 3 (M3)	*y3: Prefer Friend Sturdy Home Tornado Despite COVID-19*	Spring 2020
Model 3A (M3A)		Summer 2020
Model 4 (M4)	*y4: Prefer Friend Private Shelter Tornado Despite COVID-19*	Spring 2020
Model 4A (M4A)		Summer 2020

ground tornado shelter (such as a safe room) on their property: 17 % in Spring and 15 % in Summer (X21). The percentages were marginally lower in Summer compared to Spring due to inclusion of more northern states in the Summer survey.

Our study also provided estimates of how many households used tornado shelters at locations away from their household in the two years prior to 2020 when COVID-19 emerged. Variables X22–X24 pertained to participants' recollection of their tornado sheltering frequency in the two years prior to 2020, since the beginning of 2018 (Fig. 2). For both survey time periods, most participants (73–79 %) indicated that their household never left their home and went to a public shelter, family member or friend's shelter, or a family member or friend's sturdier home during the two years from 2018 to 2020. Those who sheltered one time at any of these locations ranged from 7 to 11 %, with slightly more participants going to a friend's sturdier home (X24) than to a public shelter (X22) or friend's shelter (X23). The share of participants who indicated their sheltering frequency was two times since 2018 was 7–8%. Between 4 and 5% indicated their sheltering frequency was 3–4 times during the two years since 2018, while the range was 2–3% for five or more times. Using these results, we computed a binary composite that represents whether participants ever sheltered outside their home in the two years since 2018: 66 % no and 34 % yes (Spring), 70 % no and 30 % yes (Summer).

4.2. Summary statistics for the dependent variables

The dependent variables (y1–y4) for all the RF models consisted of responses to survey questions asking whether participants would prefer to leave home and go to another location for shelter if a tornado threat existed in their local area, despite the emergence of COVID-19 as a public health threat in the US during 2020. The questions were posed with a 7-point Likert-type response scale in which 1 represented strong disagreement, 7 represented strong agreement, and 4 represented an uncertain or indecisive response to the question. The first two variables (y1–y2) pertain to preferences to shelter during a tornado threat at a public tornado shelter. The second two variables (y3–y4) pertain to preferences to shelter during a tornado threat at a friend of family member's location, either in their private tornado shelter (y3) or within their home as perceived to be a sturdier sheltering option (y4).

The most common response across all models was the middle category (4) indicating neither agreement, nor disagreement (Fig. 3). The percentages of respondents in this category were similar for both Spring and Summer surveys, all between 20 and 25 %. For y1, more people answered in disagreement (summing response options 1–3) whether they preferred to use a public storm shelter despite the COVID-19 pandemic, with about 48 % total in the disagreement end of the scale in both Spring and Summer. The results for y2 indicated that more people (45 %) answered in agreement (response options 5–7) that they would have been more likely to use a public storm shelter during the COVID-19 pandemic during Spring 2020 if face masks were required inside shelters. However, during Summer 2020 the percentage of respondents who answered in agreement was reduced to 38.4 %, while those who chose one of the disagreement categories (options 1–3) was 40.5 %.

Dependent variable y3 represented participants' preference to leave home and go to a tornado shelter at the residence of a friend or family member. About 45 % indicated agreement this sheltering location would be preferable in Spring, and the percentage increased to 50 % in Summer (Fig. 3). When the next question turned to sheltering within the sturdier home of a friend or family member (y4), responses were somewhat favorable in Spring (42 % in agreement) but changed to more disagreement in Summer (43 % in

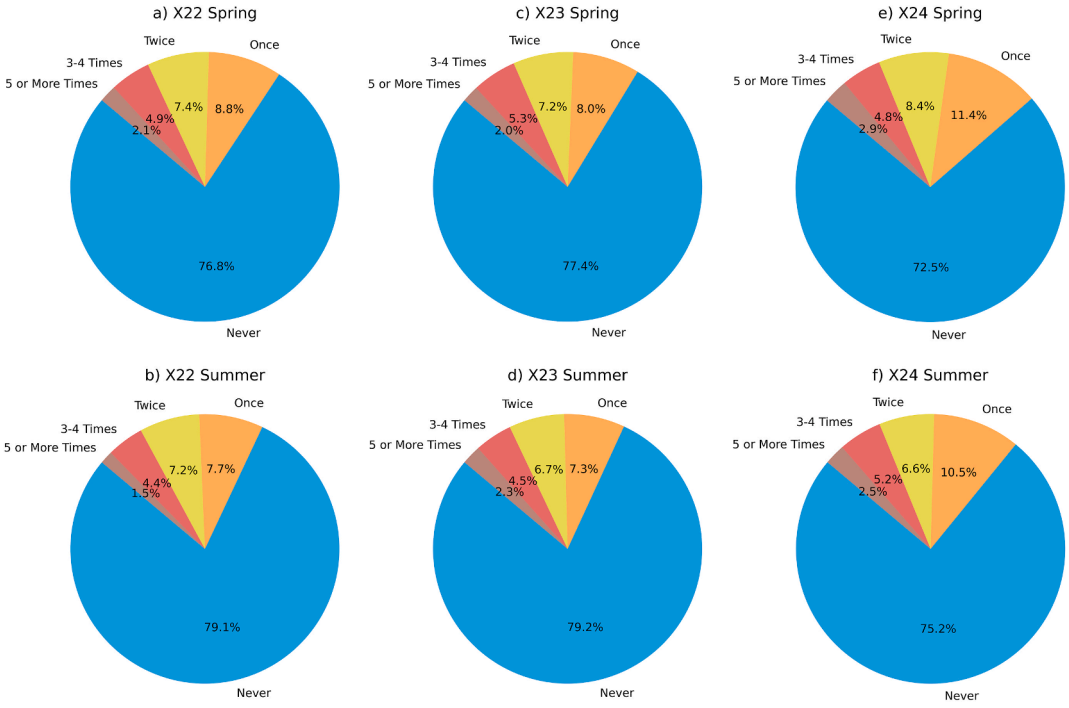

Fig. 2. Survey response percentages in Spring and Summer 2020 for independent variables (X22–X24) related to respondent tornado sheltering frequencies since 2018.

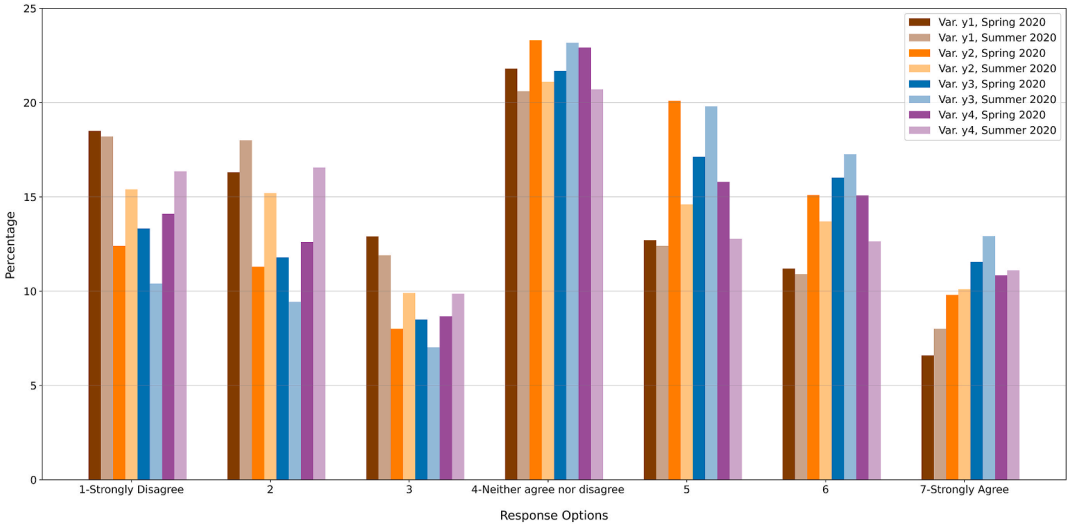

Fig. 3. Survey response percentages in Spring and Summer 2020 for dependent variables (y1–y4) related to tornado sheltering preferences.

disagreement). Across all variables, there was a pattern that respondents tended to choose the strongest disagreement (1) most frequently on the disagreement side of the scale, but on the agreement side the most frequently chosen response was the slight agreement (5).

4.3. Model 1 (M1, Spring 2020)

Independent variables with larger MDA values carried more importance (i.e., a stronger statistical relationship) in the RF models of respondent stated likelihood of use of public storm shelters during COVID-19. In model 1, seven variables drawn from four themes—generalized infectious disease risk perception, COVID-19 risk perception, availability and experience of tornado sheltering, and tornado risk perception—clearly contained more information than the others across the ensemble model suite (Fig. 4a). The two highest MDA values corresponded to variables *Perceived Disease Infectibility* (X3), the composite infectious disease risk perception measure, and *COVID-19 Risk Perception* (X5). The variable *Frequency Go Public Shelter Since 2018* (X22) was also highly important and ranked third according to the MDA values. *Perceived Disease Resistance* (X4) and *COVID-19 Negative Affect* (X6) ranked at 4th and 5th,

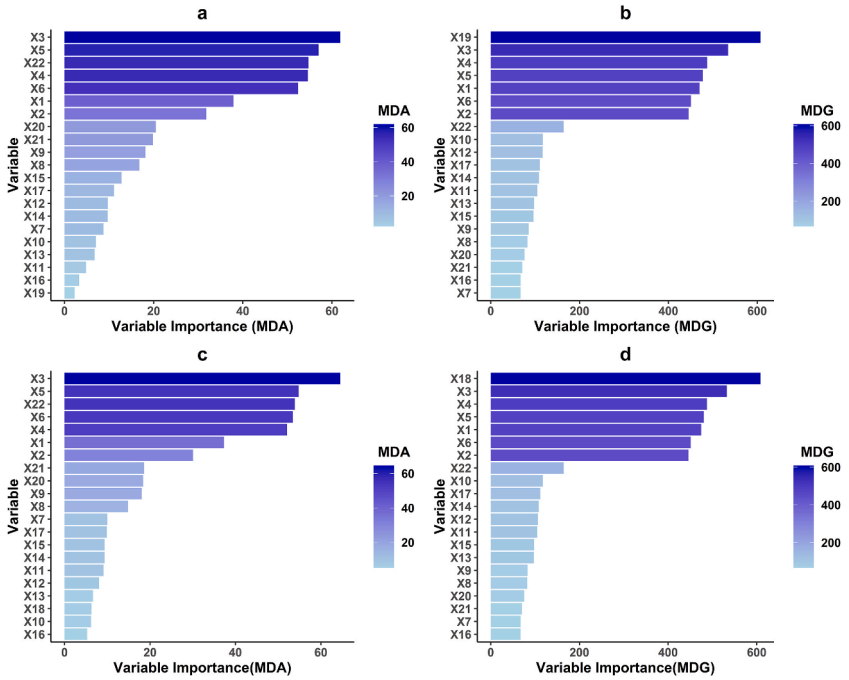

Fig. 4. Variable importance results for Model 1 (y1, Spring 2020) based on a) Mean Decrease in Accuracy (MDA) and b) Mean Decrease in Gini Impurity (MDG), and for Model 1a (y1, Summer 2020) based on c) MDA and d) MDG.

respectively. Variables *Tornado Risk Perception* (X1) and *Tornado Negative Affect* (X2) were the 6th and 7th most important independent variables in model 1. Thus, among the best predictors of preference to use public shelters during COVID-19 in Spring 2020, the four risk perception measures for COVID-19 and generalized infectious diseases were ranked in the top five. As expected, recent use of public shelters was also an influential factor. Tornado risk perception was relatively important, yet less influential for respondents than any of the four disease-related risk perception variables.

The lower MDA values were indicative of variables that had less importance in the RF ensemble suite for predicting respondents' likelihood to use a public storm shelter during the first phases of the COVID-19 pandemic in Spring 2020. Among the variables of interest that were of medium importance in this study were two indicating whether respondents indicated they have a storm shelter on their property: *Have Underground Shelter* (X20) and *Have Above Ground Shelter* (X21). There were also two housing variables of medium importance, ranked just below the shelter variables: *Mobile Homes RVs Tiny Homes* (X9) and *Single-Family House* (X8). Both housing types were more important in M1 than *Manufactured Home* (X7), as variables X8 and X9 ranked 10th and 11th and variable X7 ranked 16th among the 21 independent variables (Fig. 4a).

Variables related to gender identity and the presence of age-dependent persons (children under 18 and/or persons 65 or older) were ranked below the risk perception, on-site shelter, and housing type variables for importance in M1. The household-level presence/absence variable *Adults 65 or Older* (X15; ranked 12th) was the most important, followed by the respondent-level variable *Male Gender* (X17; 13th). The household-level presence/absence variable *Children Under 18* (X14) was ranked 14th, just ahead of the *Manufactured Home* (X7) variable. The five remaining variables were relatively unimportant in M1. These included two variables that represented the geographic location of respondents' homes within National Weather Service regions, *NWS Southern Region* (X12) and *NWS Eastern Region* (X13). The variables that represented the political affiliation of the respondents—whether *Republican* (X10) or *Democrat* (X11)—also ranked very low in importance for M1. One variable representing respondent race/ethnic identity, *Black or African American* (X16) had the second lowest MDA value. The variable *Percent All Cases New Apr May 2020* (X19) was not a strong predictor of respondents' likelihood to use a public storm shelter during COVID-19 in Spring of 2020.

In M1, the ranking of the independent variables remained largely consistent between both measures of variable importance, except for the variable *Percent All Cases New Apr May 2020* (X19) (Fig. 4b). County-level COVID-19 case data differs widely in ranks of MDA and MDG. *Percent All Cases New Apr May 2020* is a ratio level measurement and features greater variability in the possible values, which differentiates this variable from the other ordinal and categorical variables, boosting its importance to the top ranking when using the MDG measure. According to the MDG measure, the remaining top ranked variables were *Perceived Disease Infectibility* (X3), *Perceived Disease Resistance* (X4), *COVID-19 Risk Perception* (X5), *Tornado Risk Perception* (X1), *Torn Negative Affect* (X2), and *COVID-19 Negative Affect* (X6). Thus, the fear-based risk perception measure for COVID-19 (X6) was consistently less important than the exposure-based measure (X5) in M1.

The variables related to access and prior use of tornado shelters were less important using the MDG values. *Frequency Go Public Shelter Since 2018* (X22) was ranked 8th and not as important as when using MDA. *Have Underground Shelter* (X20) and *Have Above Ground Shelter* (X21) ranked 18th and 19th respectively. Finally, the housing type variables (X7, X8, and X9) had lower rankings using MDG, Thus, whether a respondent stated they lived in a site-built single-family house, a mobile home, RV, or a manufactured home did not consistently add as much useful information in M1 as the risk perception variables.

4.4. Model 1A (M1A, Summer 2020)

Model 1A (M1A) was applied to the Summer 2020 survey data and used the same dependent and independent variables as M1, except the variable *Percent All Cases New Jul Aug 2020,* which was updated to account for new cases occurring in the Summer (X18). The RF model results for variable importance were very similar to M1 (Fig. 4c). The rankings for the top seven most important variables were precisely the same as for M1. The importance of generalized infectious disease risk perception, COVID-19 risk perception, tornado shelter access and previous experience, and tornado risk perception for respondents' intentions to use a public storm shelter did not change noticeably from Spring to Summer as the COVID-19 pandemic evolved during 2020. Generalized infectious disease and COVID-19 risk perception continued to be of greater importance for model accuracy than tornado risk perception during this period.

Among sheltering availability, housing type, and household and respondent characteristics variables, many held the same rank as that of M1, while others shifted their position only slightly. According to the MDA variable importance matrix, people's preferences for using public storm shelters were less influenced by housing type, geographic region, and household or respondent characteristics than the risk perception variables (X1–X6) and recent public shelter use (X22) during Summer 2020. In the MDG matrix for M1A, the COVID-19 county cases (X18) ranked at the top, which differed greatly from the MDA variable importance matrix, but was identical to the MDG results from M1. In summary, according to the MDG importance matrix, variable influences on preference for using public storm shelters remained essentially the same from Spring to Summer 2020.

4.5. Model 2 (M2, Spring 2020)

Model 2 (M2) featured a new dependent variable (y2, *More Likely Public Shelter If Mask Required*) and the same list of independent variables as used in M1 (Table 1). The key change from y1 is that y2 added the element of face masks being required to mitigate spread of COVID-19 while in a public shelter. The most important variables for likelihood of using a public tornado shelter given a face mask requirement for M2 remained the same as for M1, with slight changes in ranking. Infectious disease risk perception, COVID-19 risk perception, and tornado risk perception corresponded to the highest values for both the MDA and MDG measures (Fig. 5a). Specifically, *COVID-19 Negative Affect* (X6) had the highest MDA value followed in rank order by *COVID-19 Risk Perception* (X5), *Perceived Disease Infectibility* (X3), *Perceived Disease Resistance* (X4), *Tornado Negative Affect* (X2), *Frequency Go Public Shelter Since 2018* (X22), and *Tornado Risk Perception* (X1).

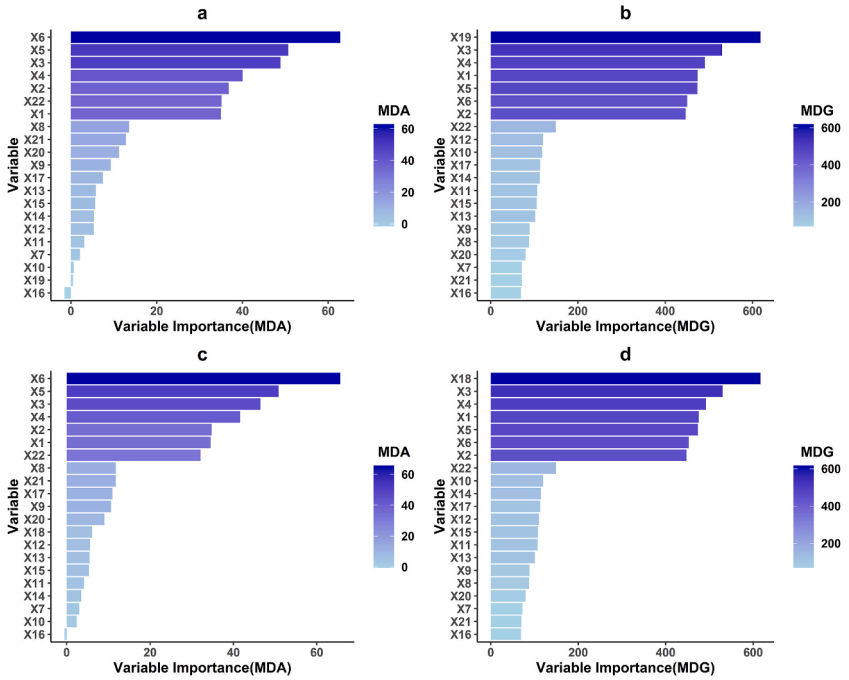

Fig. 5. Variable importance results for Model 2 (y2, Spring 2020) based on a) Mean Decrease in Accuracy (MDA) and b) Mean Decrease in Gini Impurity (MDG), and for Model 2a (y2, Summer 2020) based on c) MDA and d) MDG.

Like M1, availability of tornado shelter, housing type, household and respondent characteristics, geographic region, and county-level COVID-19 cases corresponded to medium to lower MDA values. Among housing type variables, *Single Family House* (X8) ranked highest (8th), followed closely by *Mobile Home* (X9; 11th), while *Manufactured Home* (X7) ranked much less important (18th). Availability of a tornado shelter at the resident's property (*Have Above Ground Shelter,* X21; *Have Underground Shelter,* X20) remained moderately important, ranking 9th and 10th respectively. *Male Gender* (X17), *Adults 65 or Older* (X15), and *Children Under 18* (X14) ranked highest in importance among the household and respondent characteristics. The remaining variables (X10–X13, X16, X19) were relatively unimportant according to their MDA values.

Using the MDG values (Fig. 5b), *Percent All Cases New Apr May 2020* (X19) was the most important variable followed by *Perceived Disease Infectibility* (X3), *Perceived Disease Resistance* (X4), *Tornado Risk Perception* (X1), *COVID-19 Risk Perception* (X5), *COVID-19 Negative Affect* (X6), and *Tornado Negative Affect* (X2). One key variation from the MDA results was that *Frequency Go Public Shelter Since 2018* (X22) ranked lower (8th) and was of only medium importance. Among the variables with lower MDG values, *NWS Southern Region* (X12) and *Republican* (X10) ranked much higher based on MDG than on MDA. The housing type variables (X7-X9) ranked near the bottom for MDG along with availability of tornado shelters (X20-X21) and *Black or African American* (X16).

4.6. Model 2A (M2A, Summer 2020)

Model 2A (M2A) is the Summer version of M2 that used the dependent variable *More Likely Public Shelter If Mask Required* (y2). In M2A, the top nine most important variables, according to the MDA values, were identical in ranking to the results for M2 except the interchange of rank between X1 and X22 (Fig. 5c). There was a sharp decrease in MDA values after the variable *Frequency Go Public Shelter Since 2018* (X22). The most notable difference in MDA rankings was that the COVID-19 county-level cases variable moved up from 20th in importance in M2 (X19) to 13th in importance in M2A (X18). Among the availability of tornado shelters, housing type, and household and respondent characteristic variables, *Single Family House* (X8) ranked highest but was followed closely by *Have Above Ground Shelter* (X21), *Male Gender* (X17), and *Mobile Home* (X9). Demographic variables, geographic regions, and political affiliations had lower MDA values and, therefore, were less important for the likelihood of using a public storm shelter if masks were required. In the MDG matrix, we found that, like the previous models, the COVID-19 county-level cases (X18) corresponded to the highest value (Fig. 5d). The risk perception variables for infectious diseases, COVID-19, and tornadoes followed in the ranking exactly as in M2. All other variables reflected relatively lower levels of importance in the RF ensemble for M2A.

4.7. Model 3 (M3, Spring 2020)

Model 3 (M3) featured another new dependent variable focused on sheltering in a respondent's friend or family member's home (y3, *Prefer Friend Sturdy Home Tornado Despite COVID-19*). M3 also introduced a new independent variable *Frequency Go Friend Home Shelter Since 2018* (X24), which replaced variable X22 and kept the total number of independent variables at 21 (Tables 1 and 2). In general, the most important variables for preference to shelter in a friend's sturdy home in M3 remained the same as M1 and M2 with slight changes in ranking. Among the top seven variables in MDA, *COVID-19 Negative Affect* (X6) ranked at the top followed by

COVID-19 Risk Perception (X5), *Perceived Disease Infectibility* (X3), *Tornado Negative Affect* (X2), *Tornado Risk Perception* (X1), *Perceived Disease Resistance* (X4), and *Frequency Go Friend Home Shelter Since* 2018 (X24) (Fig. 6a).

The variables of medium importance for M3 were also consistent with results from M1 and M2. Among housing type variables *Single-Family House* (X8), *Mobile Homes RVs Tiny Homes* (X9) ranked 8th and 9th respectively, while *Manufactured Home* (X7) was of little importance, ranked 20th. Among respondent and household characteristics, *Male Gender* (X17) ranked 10th and *Children Under 18* (X14) was 13th. The remaining variables had low MDA values and thus limited influence on the likelihood of sheltering within a friend's home. The importance rankings using MDG values were again very similar to the results from M1 and M2 (Fig. 6b). *Percent All Cases New Apr May 2020* (X19) ranked at the top followed by the variables for infectious disease risk perception, COVID-19 risk perception, and tornado risk perception.

4.8. Model 3A (M3A, Summer 2020)

Model 3A (M3A) examined the Summer 2020 sample and featured the same dependent variable (y3, *Prefer Friend Sturdy Home Tornado Despite COVID-19*) as M3. The top seven most important variables remained the same as M3 except the interchange of ranks between *Frequency Go Friend Home Shelter Since 2018* (X24, 6th) and *Perceived Disease Resistance* (X4, 7th) (Fig. 6c). The results for MDG aligned closely with the importance patterns shown in previous models M1A and M2A, and therefore are not outlined in detail here.

4.9. Model 4 (M4, Spring 2020)

Model 4 (M4) featured the final dependent variable (y4, *Prefer Friend Private Shelter Tornado Despite COVID*), which was distinguished from the other dependent variables by focusing on privately owned tornado shelters located at or near a respondent's friends' residences. A new independent variable, *Frequency Go Friend Shelter Since 2018* (X23), also replaced variable X24 (Table 1). Using MDA measures (Fig. 7a), *Perceived Disease Infectibility* (X3), ranked 1st followed by *COVID-19 Negative Affect* (X6), *COVID-19 Risk Perception* (X5), *Perceived Disease Resistance* (X4), *Tornado Risk Perception* (X1), *Tornado Negative Affect* (X2), and *Frequency Go Friend Shelter Since 2018* (X23).

Among variables of medium importance, *Have Underground Shelter* (X20) and *Have Above Ground Shelter* (X21) were ranked at 8th and 10th, and variables *Single-Family House* (X8) and *Mobile Homes RVs Tiny Homes* (X9) ranked 9th and 11th respectively. Political affiliation was of medium importance when using *Republican* (X10, ranked 12th), and the age-related variables *Adults 65 or Over* (X15) and *Children Under 18* (X14) were ranked 14th and 15th. Using MDG values, *Percent All Cases New Apr May 2020* (X19), ranked as most important like the other MDG measures, and was followed by the six risk perception variables (X1–X6) (Fig. 7b).

4.10. Model 4A (M4A, Summer 2020)

Model 4A (M4A) featured the same dependent variable (y4, *Prefer Friend Private Shelter Tornado Despite COVID*) as M4 but used the data from Summer 2020. The variable importance rankings for both MDA and MDG (Fig. 7d) were virtually identical to results from

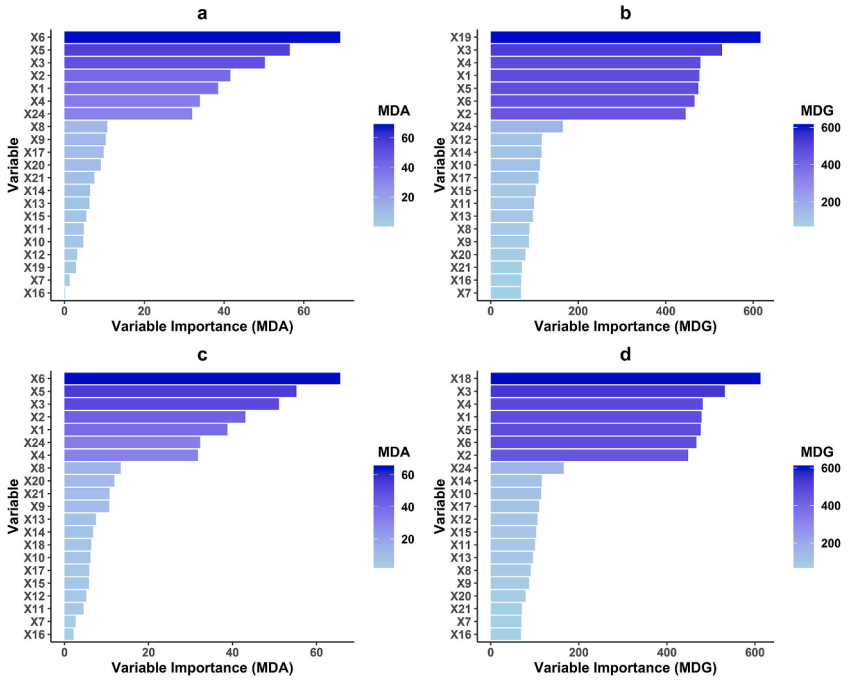

Fig. 6. Variable importance results for Model 3 (y3, Spring 2020) based on a) Mean Decrease in Accuracy (MDA) and b) Mean Decrease in Gini Impurity (MDG), and for Model 3A (y3, Summer 2020) based on c) MDA and d) MDG.

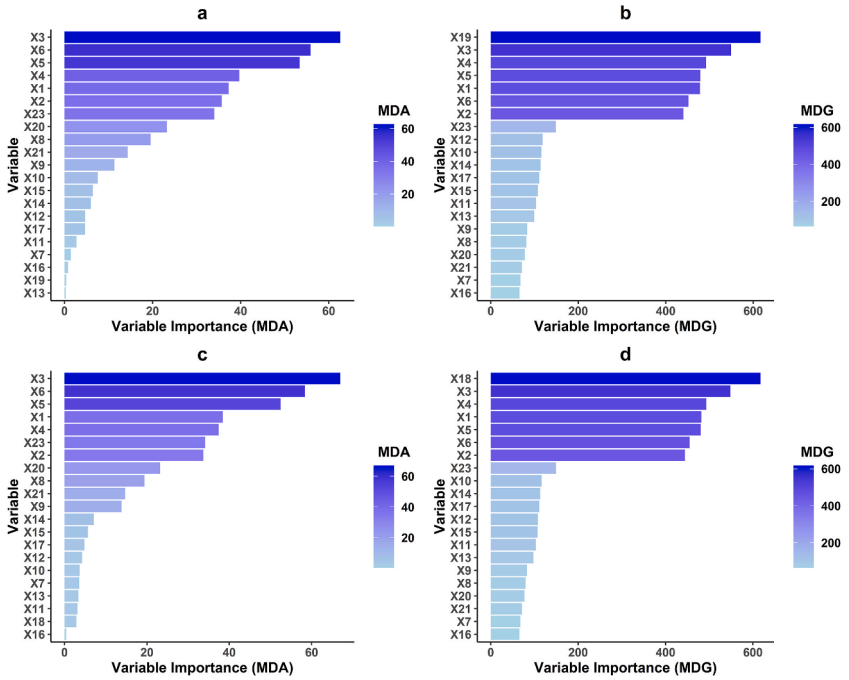

Fig. 7. Variable importance results for Model 4 (y4, Spring 2020) based on a) Mean Decrease in Accuracy (MDA) and b) Mean Decrease in Gini Impurity (MDG), and for Model 4A (y4, Summer 2020) based on c) MDA and d) MDG.

M1A–M3A. Rather than recount the variable details again, any notable interpretations from M4A will be discussed in the following section.

5. Discussion

This study used a series of ensemble models to identify the most important variables related to respondent preferences for sheltering from tornado threats during the COVID-19 pandemic in 2020. Because we reported results from eight models (four dependent variables by two survey periods, one in Spring and one in Summer 2020), here we synthesize key findings across the entire suite of models and discuss notable results for individual variables and models as appropriate.

5.1. Infectious disease risk perception measures and COVID-19 cases data

Risk perception and negative affect play a vital role in evacuation and sheltering decisions in many hazard contexts [46–49]. In this study, the risk perception measures pertaining to infectious disease risk perceptions (X3–X4), and specifically to COVID-19 risk perceptions (X5–X6), were often among the four best predictors of tornado sheltering preferences across all models (Fig. 8). *COVID-19 Negative Affect* (X6) was the most important independent variable for M2(A) and M3(A). One explanation for this result in M2(A) is that the face mask requirement could have allayed some respondents' negative feelings about being exposed to COVID-19 in a public tornado shelter. For M3(A), where the dependent variable pertained to sheltering within a friend or family member's home, the likely reason is that participants were worried about COVID-19 and did not want to risk getting the virus themselves, nor risk being the cause for friends or family getting sick. These results are generally consistent with those of Croskery and coauthors (2021) in that COVID-19 clearly influenced respondents' views and possible behaviors for tornado sheltering during 2020. However, both this study and that of Croskery et al. [7] suggested that steps to mitigate transmission of COVID-19 in group settings may alleviate some concerns, allowing people to use tornado shelters when needed while also reducing risk from infectious disease.

The variable *COVID-19 Risk Perception* (X5), which was a cognitive risk perception measure, was highly important for all models because COVID-19 was an unfamiliar, rapidly evolving threat in the US throughout the year 2020. As both COVID-19 risk perception variables were stronger predictors of tornado sheltering preferences than the tornado risk perception variables (X1–X2), most respondents were weighing COVID-19 risks as equal to or more important than tornadoes during 2020. The respondents' home county COVID-19 cases data (X18–X19) were not among the best predictors of tornado sheltering preferences for any model. However, during the Summer survey period (right half of Fig. 8) the COVID-19 cases data were more important than during the Spring period (left half of Fig. 8). This suggests that the more geographically widespread presence of confirmed COVID-19 cases during July and August 2020 was having at least a small effect on tornado sheltering preferences.

Beyond the COVID-19 risk perceptions, the infectious disease risk perception measures (X3–X4) were also highly important in all eight models (Fig. 8). *Perceived Disease Infectibility* (X3) was the most important independent variable for M1(A) and M4(A) because people who perceived they would be likely to get sick would have wanted to avoid sheltering in close quarters, such as in a public tornado shelter (M1(A) or in a friend or family member's private tornado shelter (M4(A). *Perceived Disease Resistance* (X4) was ranked

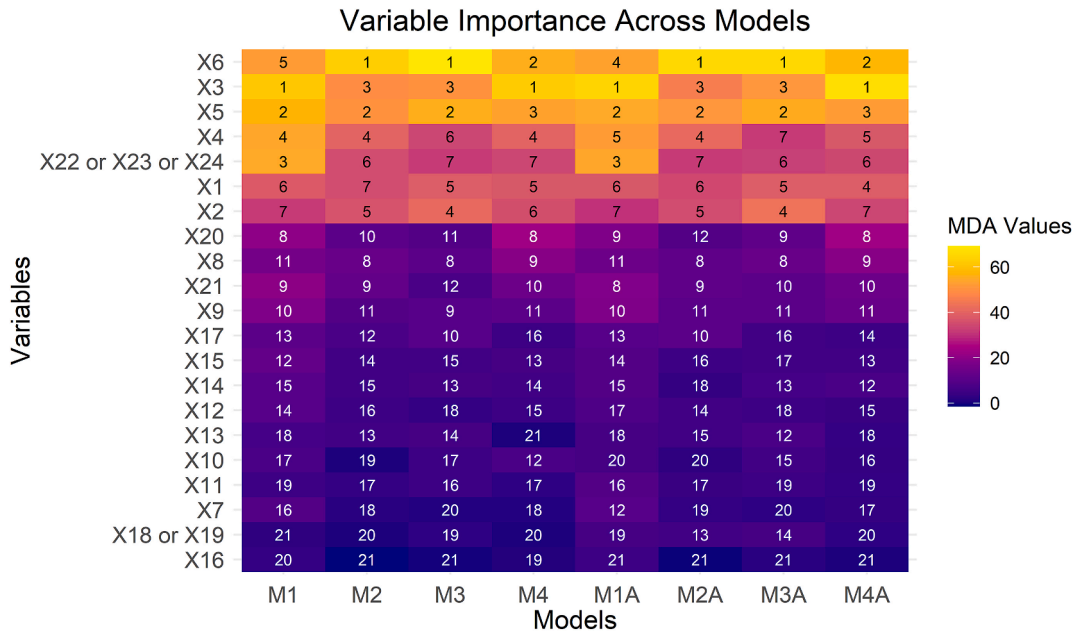

Fig. 8. Heatmap of variable importance based on MDA values from all models. Spring models are on the left half of the figure and Summer models are on the right. The ordering of the variables is descending from the top of the figure based on each variable's average MDA value across all eight models. Variables X18 and X19, as well as X22, X23, and X24, are grouped in one row because they represent the same concepts across all models. Text within each colored tile indicates the rank of variable importance within each model.

lower in importance in all models than the infectibility variable (X3), and was slightly less important during the Summer period, perhaps because people began to realize by the Summer that COVID-19 was highly transmissible, and their immune systems were not going to simply resist infection. Prior to COVID-19, some respondents could have been concerned about risks posed by a range of infectious diseases in relation to tornado sheltering with other people outside one's home. Similar concerns were noted previously among public health personnel in longer term shelters used in the post-disaster response and recovery period [50,51].

Therefore, one implication of our findings from variables X3–X4 is that some people may feel more comfortable sheltering from tornadoes in close quarters by wearing a face mask, even beyond the threat of the COVID-19 pandemic. Another interpretation of the importance of the infectious disease risk perception measures is that people were more willing to project their concerns or anxiety about COVID-19 onto a more generalized risk perception measure than to admit that COVID-19 was a major concern governing their household decision-making, given the polarized discourse that developed around COVID-19. Additionally, as noted by Croskery et al. [7], risk averse respondents tended to rate hazards as more concerning regardless of their type (tornadoes, infectious diseases, etc.).

5.2. Tornado risk perception measures, Tornado Shelter access, and recent experience

Prior to the onset of the COVID-19 pandemic in 2020, we would have expected variables related to tornado risk perception, access to a tornado shelter at one's residence, and the frequency of prior experiences sheltering at other locations to rank highest in variable importance. Though the COVID-19 and infectious disease risk perception measures were generally more important in our analyses, the tornado-related variables were still of medium to high importance in the RF models for tornado sheltering preferences. The variable *Frequency Go Public Shelter Since 2018* (X22) was ranked third for M1(A), ahead of the tornado risk perception variables and some of the disease risk perception variables as well. The other previous sheltering frequency variables (X23–X24 were still important in the remaining models but were ranked lower (6th or 7th). Thus, having previously enacted these sheltering behaviors was most relevant in the context of using a public tornado shelter.

These survey results indicate that even before COVID-19, most participants were not frequenting public or family/friends' shelters. Previously, Schmidlin et al. [3] found that 30 % of mobile home residents of select counties in four states (Georgia, Mississippi, Oklahoma, and Illinoi) went to a shelter in accordance with the recommendations of trusted authorities. Our results suggest that the share of people across all housing types who went to a public tornado shelter between 2018 and 2020 (pre-pandemic) was in the range of 21–23 %, and only 13–14 % enacting this behavior more than once over two years. Respondents living in MMHs reported previously sheltering at a friend or family member's home at a rate of almost 30 %, which aligns with the findings of Croskery and colleagues (2021) that MMH residents viewed the latter sheltering option much more favorably than public tornado shelters. These findings suggest a preference for the comforts afforded or associated with being in a home compared to what is commonly afforded or perceived to be available in public shelters.

The tornado risk perception variables (X1–X2) were, on average, the 6th and 7th most important across all models (Fig. 8). *Tornado Risk Perception* (X1), which focused on respondents' perceptions of the likelihood and severity of tornadoes in their area, was at its peak importance in M3(A) and M4(A). *Tornado Negative Affect* (X2) was at its greatest importance in M3(A) as well. This suggests

that sheltering in the home of a friend or family member is more preferred for respondents who rated tornadoes as more likely to occur and who expressed more feelings of fear and concern about tornadoes. Another finding for *Tornado Negative Affect* (X2) in M2(A) is that X2 was more important than X1. One possible explanation for this result is that the inclusion of the mask requirement at a public shelter could have allowed respondents to imagine themselves mitigating the possible impacts of tornadoes and COVID-19 simultaneously.

Finally, the two variables for access to a tornado shelter at one's residence were only of moderate importance. *Have Underground Shelter* (X20) was slightly more important in the models than *Have Above Ground Shelter* (X21). Given that only about 20 % of respondents reported having access to their own tornado shelter, those without access to their own shelter were more favorable to using a public (M1) or private tornado shelter (M4). It may be that respondents' conceptualization of what constitutes a tornado shelter may diverge from what experts would consider as a specially reinforced tornado shelter. In that case, the 20 % prevalence would be an overestimate.

5.3. Household and Respondent Characteristics

Among the variables related to household and respondent characteristics, those capturing housing type, gender, and age characteristics were most important in the RF models for tornado sheltering preferences, though they were only of medium importance when ranked against the risk perception and tornado shelter variables. Housing type was of interest because MMHs are more susceptible to damage from tornadoes than single-family fixed houses. The key information in the models was the distinction between variables *Mobile Homes RVs Tiny Homes* (X9) and *Single-Family House* (X8). Variable X8 was more important for M3(A) and M4(A) and less important for M1(A), suggesting that respondents in single-family houses were more inclined to shelter with friends or family members and less inclined to use public storm shelters. Variable X9 was most important in M1(A), indicating respondents living in mobile homes were more inclined to use public tornado shelters during the COVID-19 pandemic in 2020. The least useful variable based on housing type was *Manufactured Home* (X7). This is likely due to those in manufactured homes having mixed tornado risk perceptions depending in part on the size and/or age of their unit, as noted in previous studies [9,17].

The variable *Male Gender* (X17) was also of medium importance in the RF models of tornado sheltering preferences, especially in the context of public shelters with a face mask requirement (M2 and M2A). This result suggests that, on average, respondents who identified as men were slightly more willing than those who identified as women to expose themselves (and possibly others) to COVID-19 if a tornado threat warranted sheltering in group settings. Two variables relating to age—*Adults 65 or Over* (X15) and *Children Under 18* (X14)—were moderately important in the RF models. The results, especially in M1(A), suggested that respondents with at least one person over 65 years old in the household were less likely to use a public tornado shelter, and this was a stronger sentiment in the Spring of 2020 than later in that Summer. This result was not surprising given that older populations were advised strongly to avoid exposure to COVID-19 during the periods of this survey in 2020. Households with children younger than 18 years was a moderately important variable especially for M3(A) and M4(A) and the preference to shelter with friends or family members.

The remaining variables related to household or respondent characteristics were relatively unimportant for predicting preferences for sheltering with others in public facilities or private residences. After accounting for the more important risk perception variables, as well as tornado shelter access and previous experience with sheltering, variables such as primary political affiliation, regional location, and race/ethnicity did not provide substantial predictive power. This result is consistent with previous research in which it was common for variables such as race/ethnicity and political affiliation to be inconsistent predictors of behavioral preferences or actual protective behaviors [52].

5.4. Study limitations

This study had a few key limitations. First, the normalization of all variables into a common measurement scale was not feasible because of the variability among the variable data types (mainly ordinal, Likert-type items and binary categories). Another drawback to the use of Likert-type responses is that the semantic scale may not measurably and openly account for some participants' attitudes [53]. Second, enabling participant tracking from the first survey period to the second period would have added significant financial costs (beyond the project budget), thus Spring and Summer 2020 data sets were analyzed separately to preserve observation independence. However, there was a lost opportunity for respondent-level longitudinal analysis. Third, the research team collected data in 2020 during two peak periods of the first wave of the COVID-19 pandemic. However, data collection to track the evolution of attitudes in the subsequent years of 2021 and 2022 was not possible due to funding limitations. Thus, this study was not able to investigate possible effects on storm shelter preferences and use considering the COVID-19 vaccinations. A final caveat is that readers should take care to not necessarily apply group-level summary statistics and model results presented in this paper to individuals who live within the study area.

6. Conclusion

This research investigated the tornado sheltering preferences of people in the central and eastern US during the COVID-19 pandemic in Spring and Summer 2020. Residents living in MMHs were purposefully oversampled during data collection due to the known wind hazard vulnerability for those structures. The analysis used a Random Forest (RF) ensemble approach to model preferences for tornado sheltering in group settings during the COVID-19 pandemic, such as public tornado shelters or sheltering away from home with friends or family members. We used two metrics, MDA and MDG, to identify the most influential features in the RF model ensembles for the tornado sheltering scenarios.

The study found that the COVID-19 pandemic influenced respondents' risk perceptions and likelihood of using public tornado shelters. Cognitive and negative affective risk perceptions related to COVID-19 were better predictors of storm sheltering preferences than tornado risk perceptions during 2020. The effects of risk perception of COVID-19 on sheltering preferences remained mostly the same from Spring to Summer of 2020, both in terms of negative affect (fear, worry) and risk of exposure. Furthermore, risk perceptions for generalized infectious disease (not specific to COVID-19) were also better predictors than tornado risk perception for preferences to shelter in group settings. One of the most interesting findings was that negative affect (fear, worry) about COVID-19 was the best predictor of preference to use a public storm shelter, when the face mask requirement was included in the scenario. Likewise, the COVID-19 negative affect variable was the best predictor for preference to shelter in a sturdier home of a friend or family member.

The variables capturing the prior frequency of using public of private tornado shelters away from respondents' homes (X22–X24) were most important in the context of public shelters and were more important than cognitive or affective tornado risk perceptions. However, tornado risk perception variables were generally better predictors of preferences to shelter from tornadoes at the residence of a friend or family member. As expected, those who lived in mobile homes were more likely to use public storm shelters than those living in other housing types, though those who self-identified as living in manufactured homes did not show strong indications either way for tornado sheltering preferences. This suggests that residents' identification of their home type as manufactured home was associated with greater variability in risk perceptions than those identifying as living in mobile homes. Future research should also explore the role of infectious disease risk perception in relation to use of group tornado sheltering facilities, including but not limited to COVID-19. It may be a significant predictor of storm shelter use even in the absence of a pandemic. Though the focus here was on the tornado hazard context, this research topic could benefit from extension to other types of hazards and associated sheltering behaviors.

CRediT authorship contribution statement

Jawata A. Saba: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Christopher L. Williams:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Michael J. Egnoto:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Stephen M. Strader:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Data curation, Conceptualization. **Kim E. Klockow-McClain:** Writing – review & editing, Methodology, Funding acquisition, Data curation, Conceptualization. **Kevin D. Ash:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is published in a public data depot and the citation and DOI are given in the paper.

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Appendix 1

Table A1
Variables derived from survey questions and used in this study. Variables that begin with an 'y' denote dependent variables, whereas variables that begin with an 'X' denote independent variables. Variables without a short name or indicator (N/A) represent items used in composites or other derived versions such as binary (dummy) variables.

Variable Wording or Description	Variable Short Name	Measurement Level	Variable Indicators
Introductory Variables and Housing Type			
Combined some housing types & narrowed to five categories	N/A	Categorical; 1 = single-family house, 2 = townhome, duplex, or condo, 3 = manufactured home, 4 = mobile home, tiny home, or recreational vehicle/boat, 5 = other	N/A
Dummy Variable for Manufactured Homes	Manufactured Home	Binary; 1 = Yes, 0 = No	X7
Dummy Variable for Mobile Homes	Mobile Homes RVs Tiny Homes	Binary; 1 = Yes, 0 = No	X9

(*continued on next page*)

Table A1 (*continued*)

Variable Wording or Description	Variable Short Name	Measurement Level	Variable Indicators
Dummy Variable for Single-Family Fixed Homes	Single Family House	Binary; 1 = Yes, 0 = No	X8
Tornado Risk Perception			
"Thinking about the possibility of a tornado impacting my household makes me feel a sense of dread."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"Thinking about the possibility of a tornado impacting my household makes me feel fear."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"Thinking about the possibility of a tornado impacting my household makes me feel worried."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of 3 preceding items	Tornado Negative Affect	Ratio	X2
"I think that tornadoes are likely to occur in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I think that tornadoes are likely to cause widespread casualties (injuries & deaths) in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I think that tornadoes are likely to cause widespread hardship and disruption in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of 3 preceding items	Tornado Risk Perception	Ratio	X1
Perceived Vulnerability to Infectious Diseases			
"In general, I am very susceptible to colds, flu, & other infectious diseases."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"If any illness is 'going around', I will get it."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I am more likely than the people around me to catch an infectious disease."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I have a history of susceptibility to infectious disease."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of 4 preceding items	Perceived Disease Infectibility	Ratio	X3
"I am unlikely to catch a cold, flu, or other illness, even if it is 'going around'."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"My immune system protects me from most illnesses that other people get."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"My past experiences make me believe I am not likely to get sick even when my family or friends are sick."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of 3 preceding items	Perceived Disease Resistance	Ratio	X4
COVID-19 Risk Perception			
"Thinking about the possibility of COVID-19 impacting my household makes me feel a sense of dread."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"Thinking about the possibility of COVID-19 impacting my household makes me feel fear."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"Thinking about the possibility of COVID-19 impacting my household makes me feel worried."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of 3 preceding items	COVID-19 Negative Affect	Ratio	X6
"I think that COVID-19 is likely to be widespread in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I think that COVID-19 is likely to cause widespread casualties (serious illness & deaths) in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
"I think that COVID-19 is likely to cause widespread hardship and disruption in the county where I live."	N/A	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	N/A
Average of preceding 3 items	COVID-19 Risk Perception	Ratio	X5
Tornado Sheltering During COVID-19			
"If tornado warnings are expected or are issued for my area, members of my household would prefer to leave home and seek shelter at a designated public tornado shelter, despite the current COVID-19 situation."	Prefer Public Shelter Despite COVID-19	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	y1
"I would be more likely to use a public tornado shelter if everyone was required to wear a mask over their nose and mouth to help prevent spread of COVID-19."	More Likely Public Shelter If Mask Required	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	y2
"If tornado warnings are expected or are issued for my area, members of my household would prefer to leave home and seek shelter in a tornado shelter owned by a friend or family member, despite the current COVID-19 situation."	Prefer Friend Private Shelter Tornado Despite COVID	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	y4

(*continued on next page*)

Table A1 (*continued*)

Variable Wording or Description	Variable Short Name	Measurement Level	Variable Indicators
"If tornado warnings are expected or are issued for my area, members of my household would prefer to leave home and seek shelter in a sturdier home owned by a friend or family member, despite the current COVID-19 situation."	Prefer Friend Sturdy Home Tornado Despite COVID	Interval; 1 = Strongly Disagree to 4 = Neither agree nor disagree to 7 = Strongly Agree	y3
Availability of and Experience with Tornado Shelters			
"Does your household have an underground tornado shelter on your property?"	Have Underground Shelter	Binary; 1 = Yes, 0 = No	X20
"Does your household have a reinforced above ground tornado shelter on your property, such as a safe room?"	Have Above Ground Shelter	Binary; 1 = Yes, 0 = No	X21
"In the past two years, since the beginning of 2018, how often has your household left home and gone to a public tornado shelter, due to the threat of tornadoes? Please choose only one answer."	Frequency Go Public Shelter Since 2018	Interval; 0 = Never, 1 = Once, 2 = Twice, 3 = 3–4 Times, 4 = 5 Times or More	X22
"In the past two years, since the beginning of 2018, how often has your household left home and gone to a tornado shelter owned by a friend or family member, due to the threat of tornadoes? Please choose only one answer."	Frequency Go Friend Shelter Since 2018	Interval; 0 = Never, 1 = Once, 2 = Twice, 3 = 3–4 Times, 4 = 5 Times or More	X23
"In the past two years, since the beginning of 2018, how often has your household left home and gone to a sturdier home owned by a friend or family member, due to the threat of tornadoes? Please choose only one answer."	Frequency Go Friend Home Shelter Since 2018	Interval; 0 = Never, 1 = Once, 2 = Twice, 3 = 3–4 Times, 4 = 5 Times or More	X24
Household and Respondent Characteristics			
"Including yourself, please indicate the number of people in your household that fall within each age category below: Under 6 years of age; 6 to 17; 18 to 34; 35 to 49; 50 to 64; 65 to 74; 75 to 84; 85 or older"	(Represented by multiple variables in master file)	Integer answers filled in for each category	N/A
Presence of Children in Household	Children Under 18	Binary; 1 = Yes, 0 = No	X14
Presence of Elderly in Household	Adults 65 or Older	Binary; 1 = Yes, 0 = No	X15
"Please indicate your gender identification."	N/A	Categorical; 1 = Male,2 = Female, 3 = Non-Binary, 4 = Prefer not to say	N/A
Male Gender Identification	Male Gender	Binary; 1 = Yes, 0 = No	X17
"Please indicate the racial heritage(s) with which you identify. Please select all that apply."	N/A	Categorical; 1 = White, 2 = Black of African American, 3 = American Indian or Alaska Native, 4 = Asian, 5 = Native Hawaiian or Pacific Islander, 6 = Other (with space to answer)	N/A
Black or African American Identity	Black or African American	Binary; 1 = Yes, 0 = No	X16
"What do you consider to be your primary political affiliation? Please choose only one answer."	N/A	Categorical; 1 = Democrat, 2 = Republican, 3 = Independent, 4 = Libertarian, 5 = Green Party, 6 = Constitution Party, 7 = Other (with space for answer)	N/A
Dummy Variable for Democrat	Democrat	Binary; 1 = Yes, 0 = No	X11
Dummy Variable for Republican	Republican	Binary; 1 = Yes, 0 = No	X10
Dummy Variable for NWS Southern Region	NWS Southern Region	Binary; 1 = Yes, 0 = No	X12
Dummy Variable for NWS Eastern Region	NWS Eastern Region	Binary; 1 = Yes, 0 = No	X13
County Level COVID-19 Case Data			
Percentage of cumulative number of cases (beginning 2 Feb) that were reported from 28 Apr to May 28, 2020	Percent All Cases New Apr May 2020	Ratio; number of new cases during recent period divided by total number of cases since Feb 2, 2020; expressed as percentage	X19
Percentage of cumulative number of cases (beginning 2 Feb) that were reported from 29 Jun to Aug 6, 2020	Percent All Cases New Jun Aug 2020	Ratio; number of new cases during recent period divided by total number of cases since Feb 2, 2020; expressed as percentage	X18

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