Tornado Climatology and Risk Perception in Central Oklahoma

VICTORIA A. JOHNSON,[a] KIMBERLY E. KLOCKOW-MCCLAIN,[b,c] RANDY A. PEPPLER,[b,a] AND ANGELA M. PERSON[d,a]

[a] *Department of Geography and Environmental Sustainability, University of Oklahoma, Norman, Oklahoma*
[b] *Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, Oklahoma*
[c] *NOAA/National Severe Storms Laboratory, Norman, Oklahoma*
[d] *Christopher C. Gibbs College of Architecture, Norman, Oklahoma*

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ABSTRACT: Residents of the Oklahoma City metropolitan area are frequently threatened by tornadoes. Previous research indicates that perceptions of tornado threat affect behavioral choices when severe weather threatens and, as such, are important to study. In this paper, we examine the potential influence of tornado climatology on risk perception. Residents across central Oklahoma were surveyed about their perceptions of tornado proneness for their home location, and this was compared with the local tornado climatology. Mapping and programming tools were then used to identify relationships between respondents' perceptions and actual tornado events. Research found that some dimensions of the climatology, such as tornado frequency, nearness, and intensity, have complex effects on risk perception. In particular, tornadoes that were intense, close, and recent had the strongest positive influence on risk perception, but weaker tornadoes appeared to produce an "inoculating" effect. Additional factors were influential, including sharp spatial discontinuities between neighboring places that were not tied to any obvious physical feature or the tornado climatology. Respondents holding lower perceptions of risk also reported lower rates of intention to prepare during tornado watches. By studying place-based perceptions, this research aims to provide a scientific basis for improved communication efforts before and during tornado events and for identifying vulnerable populations.

KEYWORDS: Social Science; Tornadoes; Climatology; Risk assessment

1. Introduction

Each year, over 1000 tornadoes affect the United States on average, leaving many thousands of people to recover and reassess their risk of subsequent events (NOAA 2019a). For a small portion of these tornadoes, research has been conducted to understand aspects of the disaster, including the demographic and situational factors that drive casualties in tornadoes (Schmidlin and King 1995, 1997; Schmidlin et al. 1998; Daley et al. 2005; Biddle 2010; CDC 2012), how false alarms may influence warning response and casualties (Simmons and Sutter 2008; Ripberger et al. 2015; Trainor et al. 2015), the ways tornado casualties may change with risk exposure (Ashley and Strader 2016), the preferences people have for lead time in tornadoes (Hoekstra et al. 2011), and the ways that National Weather Service (NWS) warnings were received, understood, and acted upon during particular events (Hammer and Schmidlin 2002; Schmidlin et al. 2009; Schultz et al. 2010; Klockow 2011; NWS 2008, 2011a,b; Senkbeil et al. 2012; NWS 2014). This variety of works has revealed that there are numerous factors that ultimately shape behaviors and outcomes, including objective risk factors like exposure and vulnerability and subjective factors like individual perceptions of risk.

The perception of risk, defined as the intuitive judgment individuals make about the likelihood of a threat and its consequences (Slovic 1987), is one of the strongest predictors of behavior in hazard events overall, including the tendencies to prepare for and respond to warning information (e.g., Lindell and Perry 2012; Dow and Cutter 2000; Mileti and Sorensen 1990). It is thus important for risk communicators to understand these perceptions as they form so they can account for these intuitive judgments in their risk communication strategies (Brown et al. 2016; NOAA 2019b). Several theoretical perspectives explain how individuals come to their perceptions of risk for a given hazard, each offering a unique dimension of influence. Some of the most prominent paradigms demonstrate that risk perceptions are shaped by attributes inherent to the threat itself, known as the psychometric paradigm (Slovic 1987), by the way the risk is amplified or attenuated among social groups and other influencers (Kasperson et al. 1988), and by the way the risk fits in with—or pushes against—the preferred ways of life of individuals exposed to it (Douglas and Wildavsky 1982). A dominant theory encompassing concepts of space and place—ideas that may be very consequential for tornado risk perception—has yet to emerge (Klockow et al. 2014). Importantly, risk perceptions may also change based on updated information and experiences with a hazard (Lindell and Perry 2012), and it may thus be just as important for risk communicators to know how to keep up with these changes so their strategies can be updated. Recent research has begun to explore how perceptions of tornado risk in particular can change, especially in light of previous experience with tornadoes (Suls et al. 2013; Silver and Andrey 2014; Klockow et al. 2014; Demuth 2018; Ellis et al. 2018; Peppler et al. 2018).

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Corresponding author: Victoria A. Johnson, johnsonvictoria@ou.edu

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An outstanding question in this literature relates to the way that attributes of previous tornado events, including their proximity to an individual in space and time and their intensity, may affect perceptions of risk.

a. Tornado risk perception: Space and place

Some past studies point to the importance of space and place in forming risk perceptions about tornado threat, but the results are mixed. At a high level, tornado events that occur directly to oneself or indirectly through others (i.e., family, friends, or events shown on news media) both influence the perception of risk, which means experience resonates when an event is both in their place of residence and in other places (Demuth 2018). People who live in regions that are generally characterized by higher objective tornado likelihood also tend to perceive more risk from that hazard (Allan et al. 2020). Other research demonstrates that people attend to very *local* tornado climatology and use it to construct more refined ideas about tornado risk in their place of residence (Suls et al. 2013; Klockow et al. 2014; Ellis et al. 2018; Peppler et al. 2018). Ellis et al. (2018) indicated that people who had general experience (i.e., both direct and indirect) with tornadoes had higher perceptions of climatological threat in their county. Residents often underestimated their climatological threat for tornado risk; however, the perception of risk was higher for those with experience than those with no prior experience. Suls et al. (2013) conducted a postevent study of the Parkersburg, Iowa, 2008 tornado and found that people who were in the immediate path of the tornado felt less at risk from subsequent storms than areas surrounding the path. Thus, direct experience in the immediate aftermath of a storm may actually decrease perceptions of risk for subsequent storms—an apparent application of the gambler's fallacy, a cognitive bias where individuals believe that a particular outcome becomes less likely in future trials if it was just experienced (Croson and Sundali 2005).

Other past studies complicate this idea, however. Klockow et al. (2014) examined place-based perceptions of risk for individuals who had experienced tornadoes in the 27 April 2011 tornado outbreak in Alabama and Mississippi. As the tornadoes headed their way, these individuals reported attending to physical and cultural features (rivers, hills, urban landscapes, local cultural legends, etc.) to amend how they perceived risk for their location. An apparent spatial form of optimism bias, these ideas were often protective in nature. If tornadoes in the past had been close but "didn't hit me" (i.e., no direct experience), people perceived their personal risk to be lower, and felt some sense of protection as tornadoes neared that day. There is a notable exception, however. For two consecutive years, 2009 and 2010, Cordova, Alabama, was struck by tornadoes and felt particularly at risk when storms were impending in 2011, in part because a new highway was constructed that cleared out what were perceived as protective hills and forests. Therefore, in contrast with the finding by Suls et al. (2013), direct experience could heighten the perception of risk immediately after a tornado if there were multiple recent experiences. The effect of time will be discussed further below.

In addition, Peppler et al. (2018) found that in central Oklahoma particular places have taken on risk-prone status, while some communities near those places may feel relatively safe. They note, for example, that residents in Norman feel much less at risk to tornadoes than those residing in Moore. In general, places southwest of urban areas reported feeling more risk prone, whereas places northeast, or "downwind" of the urban area reported feeling less risk prone. This research points to the potential existence of spatial risk perception heterogeneities on multiple scales.

b. Tornado risk perception: Time

Risk perception also can be influenced by the passage of time, because major events could endure in memory after several years and still influence one's perception of risk (Demuth 2018). Some studies show considerable variations in tornado risk perception over time, but this relationship is multifaceted. Suls et al. (2013) found that individuals in the path of the Parkersburg tornado reported feeling less at risk than the surrounding area up to 6 months after the event. By one year after the event, risk perception values between those directly affected and in the immediate area were statistically identical. Notably, people in areas surrounding the tornado path also felt less vulnerable to future tornadoes at 1, 6, and 12 months after the event—the effect on this population was just smaller than those in the immediate impact zone. Thus, both groups felt some degree of optimism from being in or close to the tornado, and the added effect of being in the immediate path eroded quickly, leaving a more evenly distributed regional optimism. Opposing this finding, Silver and Andrey (2014) investigated changes in risk perception over time for an entire community, Goderich, Ontario, Canada, that had been hit by a tornado. They found that perceptions of risk proneness and the propensity to take protective action by citizens of Goderich (i.e., individuals close to the damage path) increased in the immediate aftermath of the tornado. When an event occurred in the same location three days later, the population was much more responsive than they had been for the first event. Therefore, it is difficult to generalize an effect of time from available case studies; further research is needed to clarify this matter and to identify broader patterns across time scales.

c. Tornado risk perception: Intensity

Research examining the effect of tornado intensity on risk perception, a factor that relates to the intuitive judgments that individuals form about the consequences of a hazard, appears sparse, because most case studies have been performed on the most intense tornadoes only, and for single tornado events. Feelings of risk proneness may not be affected as strongly when residents have been impacted by weaker (EF0–EF2 on the enhanced Fujita scale) tornadoes. This may partially explain why the Oklahoma communities of Norman and Moore have such different perceptions of tornado risk, though both have suffered tornadoes—many of the strongest tornadoes to affect Norman recently hit the outskirts of the community, and most of the tornadoes to hit Norman's urban core have been nonviolent (Peppler et al. 2018). More work is needed that examines the effects of tornadoes of all intensities on risk perception, including weaker tornadoes.

d. Research approach and hypotheses

From this review of previous literature, we hypothesize that the dimensions of space, time, and tornado intensity may affect perceptions of tornado risk in nuanced and potentially interconnected ways, and not simply be a linear function of space, time, or intensity alone. In an attempt to reconcile the previous literature, our research examines risk perception across central Oklahoma (Fig. 1) when considering all of these dimensions together. By considering the tornado climatology and pairing it with placed-based perceptions of risk, we identify particular windows of time and space that are significant in shaping those perceptions. This provides a fundamentally different approach to understanding tornado risk perceptions than work undertaken previously that focused on single events.

2. Data and methods

a. Sampling and survey collection

This study leverages a survey dataset collected on the authors' behalf by the University of Oklahoma's Public Opinion Learning Laboratory (OU POLL) during spring 2016. A total of 463 survey responses were gathered, and each respondent's latitude–longitude coordinates and zip codes were recorded along with their survey responses. The survey first asked respondents to report their perceived level of tornado risk for their own town. This question was, "Please rate how tornado-prone you believe your current city or town is using a scale from *zero* to *ten*, with *zero* meaning *no* vulnerability and *ten* meaning *very high* vulnerability."[1] Additional items were included but are not analyzed here and can be found in the supplemental online materials.

The risk perception score was created in 2012 using a focus group of Norman residents, with the objective to create a measure that would account for differences in the way people viewed tornadoes' propensity to affect particular places on a community scale. The inspiration for this measure was local knowledge that suggested individuals felt tornadoes were more drawn to particular communities than others. This draft measure was pilot tested in a series of town hall meetings (Peppler et al. 2018), in which residents of the Oklahoma towns of Norman, Newcastle, and Moore—neighboring communities with very different tornado folklore and experiences—came to local meetings and answered survey questions, including this question, and then participated in focus group discussions. Through these focus group discussions, it was determined that

FIG. 1. Central Oklahoma counties from which the sample population was drawn for this study.

people answered the question in such a way that the scale reflected true underlying beliefs: places that reported a qualitative sense of higher community risk proneness had higher scores than those reporting a lower sense of community risk proneness (Peppler et al. 2018). As noted earlier, the town halls revealed a substantial difference in tornado risk perceived by residents of these adjacent municipalities, which stood in contrast to the recorded frequency of tornado occurrence. To investigate these relationships more directly, this measure was then applied in the 2016 survey, where we aimed to gather a large enough sample across the region that we could perform statistical analyses and understand in more depth the relationship between climatology and risk perception. Importantly, this measure focuses on only a particular aspect of overall tornado risk perception: the intuitive judgments people make about the likelihood that their local area will incur a tornado.

b. Tornado tracks

Survey data were layered with tornado tracks available at the NOAA/National Weather Service Storm Prediction Center Severe Weather geographic information system (GIS) (SVRGIS) web page (NOAA 2019b). It is a database that contains NWS storm data for tornadoes, hail, and damaging winds dating to 1950. The reports have been converted into shapefile (.shp) format for GIS analysis. For each tornado in the database, its date, time, path geolocation (latitude–longitude), intensity (EF0–EF5, or EF9 for unknown intensity),

[1] The scale reference was adjusted from "likelihood" to "vulnerability" by OU POLL to make the question easier to answer. Likelihood and vulnerability, however, are slightly different concepts; any consequence for participant interpretation is unknown, especially since the technical difference is not likely to be well understood by nonexpert populations.

TABLE 1. The t tests showing the difference in average risk perception ratings for respondents who have experienced an intense tornado (EF3–EF5; $n = 19$ tornadoes) and those who have not, stratified by time since and distance from tornadoes. Boldface entries indicate a positive effect where risk rating increased by 1 or more. Instances in which the sample size of a particular category is not statistically representative ($n \leq 30$) contain a dashed line, and no statistical analysis was performed. One, two, or three asterisks indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

	1 mi	5 mi	10 mi	15 mi	20 mi
1 yr	—	—	—	—	—
5 yr	—	**1.3*****; yes: 80; no: 383	0.4; yes: 225; no: 238	0.4; yes: 323; no: 150	0.1; yes: 387; no: 76
10 yr	—	0.7***; yes: 162; no: 301	0.7***; yes: 283; no: 180	—	—
20 yr	0.8*; yes: 66; no: 397	0.7***; yes: 211; no: 252	0.4**; yes: 334; no: 129	—	—

and the number of injuries and fatalities are recorded. Oklahoma tornadoes for the period 1996–2016 were manually selected and extracted from the database and were separated into time periods of occurrence, including within the past 1, 5, 10, and 20 years. Since survey data were collected in 2016, that year became the end date for constructing climatology. For 1996–2016, 186 tornadoes with damage ratings were defined in total, and 4 tornadoes of unknown intensity (EF9) were excluded from the dataset. Tornado intensity, path location, and date/time were the central attributes that composed the analysis to follow.

c. *Data analysis*

1) GIS AND ARCGIS ANALYSIS

The first stage of the analysis was GIS-based to help us understand the distribution of tornadoes and its relationship to the locations of the respondents in our study. Respondents were mapped utilizing the software package ArcGIS, using their latitude–longitude coordinates; however, in cases where no latitude–longitude was provided, respondents were mapped to the centroid of their zip code (105 respondents). A spatial join was then used to relate average tornado risk perception by zip code. Next, tornado track data for the 186 tornadoes identified were incorporated into the survey dataset. Then an analysis was performed to relate the tornadoes in the database to each respondent; this analysis identified minimum distances from each respondent to each tornado track. These results were compiled to reveal the number of tornadoes each respondent experienced per certain criteria; for example, to identify the number of tornadoes $\geq$ EF4 that occurred within the last 5 years and within 5 mi (1 mi $\approx$ 1.6 km) of the respondent.

2) STATISTICAL ANALYSIS USING R

Next, independent t tests were computed using the statistical software environment R. These were used to determine whether there was a significant difference between group means for factors such as distance from, time since, and intensity of a tornado. Analyses were conducted at three categories of intensity (EF0–EF5, $\geq$EF3, and $\geq$EF4) using all combinations of times since tornado (1, 5, 10, and 20 years) and distances from a given tornado path (1, 5, 10, 15, and 20 mi). In theory, for example, these t tests would reveal the difference in average risk perception for respondents who had experienced violent ($\geq$EF4) tornadoes within 5 mi and the last 5 years as compared with those who did not meet those criteria. We attempt to reveal the effects of time, distance, and intensity independent of one another through a series of Kruskal–Wallis H tests.

3. Results and discussion

We hypothesized that respondent perceptions of risk increase with closer proximity in space and time and increased with tornado intensity. We additionally hypothesized that these variables may explain observed heterogeneities in risk perception between adjacent or nearby areas (as noted in Peppler et al. 2018). The sample size of the survey was 463 respondents. Our results are presented below.

a. *Three-dimensional relationships: Time, distance, and intensity*

A total of 463 individuals responded to our survey. The sample was 63.64% female (number $n = 294$) and 36.36% male ($n = 168$), and respondents ranged from 18 to 96 years of age (mean $\mu = 64$; standard deviation $\sigma = 14$). Educational attainment levels ranged from less than high school completion to doctoral degrees (average around associate degree). Annual household income levels ranged from \$1,100 to \$400,000 ($\mu = \$67,753$; $\sigma = \$57,142$). Thus, the sample skewed older, more female, and wealthier than the median for the state of Oklahoma. We asked respondents how long they had lived at their current location and how long they had lived in Oklahoma. Participants had lived in their current town of reporting from 0 to 68 years ($\mu = 18$; $\sigma = 14$), and within central Oklahoma from 0 to 94 years ($\mu = 42$; $\sigma = 22$). Overall, the sample represents citizens with many years of experience in the region.

The average perception of risk among all respondents was 6.41, with a standard deviation of 2.34, and values ranged from 0 to 10. We found that time, distance, and intensity all partially explained variability in risk perception scores; however, the patterns were not as simple as we had hypothesized. In fact, we identify here two distinct effect patterns. As shown in Tables 1 and 2, having an intense ($\geq$EF3), nearby (within 5 mi) tornado in the last 5 years increased mean risk ratings by 1.3 at a significance level of $p < 0.001$. This first effect confirms our hypothesis but, more important, only for tornadoes of high intensity. In looking down the columns in Tables 1 and 2 and thereby including the effects of tornadoes occurring

TABLE 2. As in Table 1, but for EF ≥ 4 intensity, with $n = 10$ tornadoes.

	1 mi	5 mi	10 mi	15 mi	20 mi
1 yr	—	—	—	—	—
5 yr	—	**1.3*****; yes: 73; no: 390	0.3; yes: 204; no: 259	0.4; yes: 301; no: 162	0.1; yes: 387; no: 76
10 yr	—	**1.2*****; yes: 83; no: 380	0.4; yes: 231; no: 232	**1.2***; yes: 418; no: 45	
20 yr	0.7*; yes: 34; no: 429	0.9***; yes: 138; no: 325	0.4; yes: 302; no: 161	—	—

farther out in time, it is seen that the effect is still positive but smaller ($t = 0.7$; $p < 0.001$). Similarly, in looking across the rows in Tables 1 and 2, it is seen that more spatially distant tornadoes tended to have small positive, yet nonsignificant, effects on tornado risk perception ($t = 1.6$; $p < 0.1$). There are interesting exceptions to these trends. In Table 2, for example, risk perception spikes significantly due to tornadoes within 10 years and 15 mi ($t = 2.9$; $p < 0.05$). This exception is examined in more detail in the following geospatial analysis section. In summary, however, risk ratings for the most intense tornadoes decrease as time and distance from the track increase, possibly indicating that when a tornado is not seen over a long period its effect diminishes.

The second pattern involves relatively weak tornadoes. Table 3 shows statistical significance ($p < 0.001$) for a *negative* shift ($t = -0.7$) in perceived risk when tornadoes occurred within the past year and within 10 mi of the respondent. This outcome raises the possibility for an inoculating effect where respondents feel less risk prone when they are close to particular kinds of tornadoes. Beyond its use as a medical concept, where a small exposure to a disease causes the body to build an immunity to it, inoculation has also been leveraged in the social sciences to describe how exposure to one idea can lead a person to resist other ideas (e.g., Banas and Rains 2010; Banas and Miller 2013; Compton 2019). In this case, we use it to indicate that past exposure to a relatively weak tornado may lead individuals to feel less threatened with regard to potential future events. In other words, perceptually, it seems that exposure to a "low dose" tornado leads these individuals to resist the idea that tornadoes are concerning. Since there are many more weak (≤EF2) tornadoes ($n = 167$) than there are intense ones (≥EF3; $n = 19$) in the database, these results suggest that the number of tornadoes alone do not produce a positive effect, but the experience of particularly intense (≥EF3) and recent (≤10 yr) tornadoes.

The preceding analysis specified unique combinations of time, distance, and intensity to reveal broad patterns. Next, we attempt to move beyond specific combinations to examine whether general effects exist for time, distance, and intensity alone. To isolate the potential effect of time, we generated a Kruskal–Wallis H test to check for differences in risk perception among groups that have experienced tornadoes within the past 1, 5, 10, or 20 years. To generate this test, we used the least restrictive bounds for both distance and intensity (20 mi and tornadoes of intensity EF0–EF5). The Kruskal–Wallis H test demonstrated almost no variability in risk perception among these groups. We reach the same result for distance and intensity. The analysis reveals that tornadoes do not cumulatively generate influence with any single factor alone; individuals that have experienced any kind of tornado within a large radius in the past year feel much the same about their local tornado risk as individuals that have experienced and kind of tornado within a large radius in the past 20 years. Mathematically, the Kruskal–Wallis H test fails to isolate populations with unique perceptions of risk; thus, it is the combination of these three attributes that gives rise to differences in risk perception. We include the results of the Kruskal–Wallis H tests in appendix A.

b. Spatializing tornado risk

In addition to the described risk perception measures, we sought to identify spatial variations in context. Below, we examine relationships at the regional level and for a unique set of neighboring towns. Figure 2 provides context for this analysis, depicting risk perception by heat map, sample, size, and the spatial relationship between survey respondents and tornado tracks. Figure 2a is formatted into a heat map that easily depicts the relationships of interest while offering clear place names to orient the viewer. Figure 2b separately indicates the density of observations drawn from places with particular risk perception characteristics; this was done to emphasize areas where sample sizes were large.

Perceptions of risk vary considerably across central Oklahoma (Figs. 2a,b). In general, heightened feelings of risk exist southwest of Oklahoma City and feelings of risk are lower just east and north of the city (Peppler et al. 2018). Figure 3 utilized a buffer analysis to identify the locations of respondents in relation to specified distances (e.g., 1, 5, 10, 15, or 20 mi) from a particular tornado. Here, we examine those trends in light of the spatiotemporal relationships between

TABLE 3. As in Table 1, but for EF0–EF5 intensities, with $n = 186$ tornadoes.

	1 mi	5 mi	10 mi	15 mi	20 mi
1 yr	—	—	−0.7***; yes: 224; no: 239	−0.2; yes: 366; no: 97	−0.1; yes: 433; no: 30
5 yr	0.4; yes: 80; no: 383	—	—	—	—
10 yr	0.1; yes: 156; no: 307	—	—	—	—
20 yr	0; yes: 210; no: 253	—	—	—	—

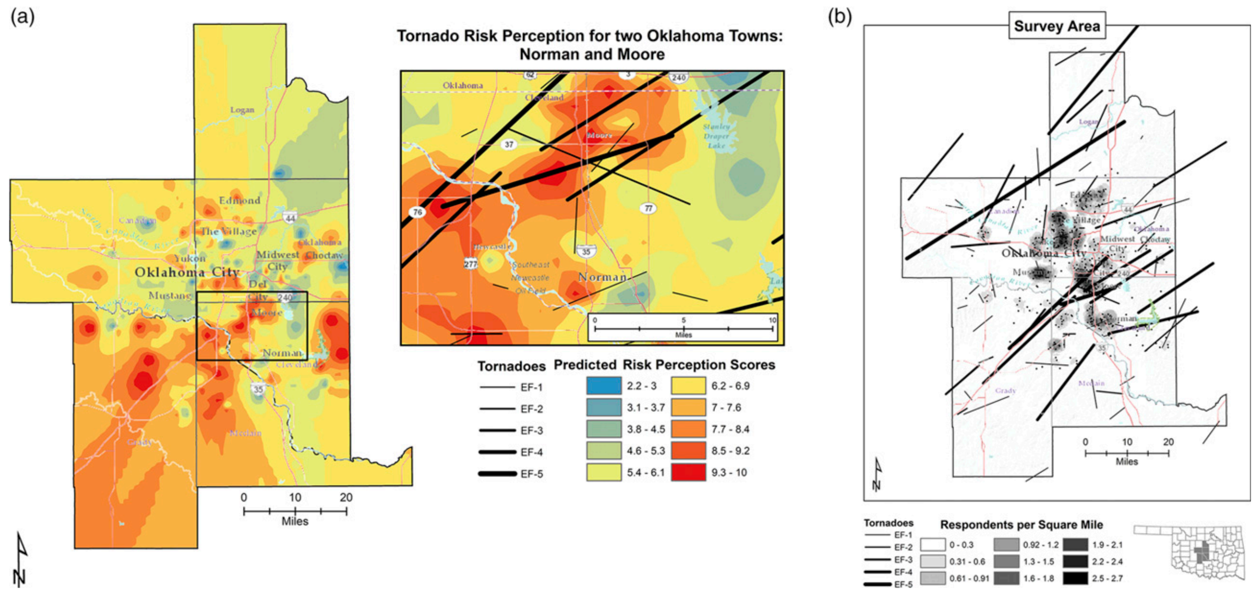

FIG. 2. (a) Heat map depicting average risk perception for communities within central Oklahoma. A zoomed-in inset map highlights the Moore–Norman findings from Peppler et al. (2018) and is overlaid with tornado tracks (1996–2016). (b) Survey respondent locations and population density (n = 463) in relation to tornado tracks (1996–2016).

respondents and tornadoes of varying intensity that were identified as statistically significant in the t-test analyses (Fig. 3). Most important, many of the respondents north and east of the city have not yet experienced an intense (≥EF3) tornado within 5 mi and 10 years (Fig. 3, label 3C). This may explain the regional differences between the southwest and northeast portions of Oklahoma City (OKC). Much of the OKC metropolitan area has experienced a nonviolent tornado within 2016 and 10 mi (Fig. 3, label 3A), and also a violent (≥EF4) tornado within the last 10 mi and 10 years (Fig. 3, label 3J); therefore, regional differences may be explained more by tornado space/time/intensity combinations than folk science ideas proposed in Peppler et al. (2018).

Interestingly, broad regional trends do not always apply to municipalities within those regions. Building upon Peppler et al. (2018), one of the most interesting findings from the 2012 central Oklahoma Town Hall meeting analysis was the differences in tornado risk perceived by respondents living in two adjacent municipalities south of OKC, Moore and Norman (see Fig. 2a). This area generally displayed a higher perception of risk than areas to the north of OKC. Analysis using these survey data confirm the Moore–Norman differences shown in Peppler et al. (2018). Moore was found to have an average risk perception rating of 9.7, while Norman had a rating of 6.5. Both analyses confirm that respondents, regardless of where they live, feel Moore is more likely to be struck by tornadoes than Norman. The third municipality analyzed in Peppler et al.'s (2018) study, Newcastle, which is just southwest and west of Moore and Norman, respectively, had an average risk perception rating of 8.1, which also confirms the Peppler et al. (2018) result. All three towns had relatively large sample sizes ($n \geq 11$; n total = 80) in the present survey.

Some respondents reported that their heightened or diminished sense of risk was due to the presence of geographical features, such as the Canadian River that separates Newcastle from Moore and Norman, or elevation differences among these three locations (Peppler et al. 2018). Regardless, it is clear from this example that some heterogeneities in risk perception are tied to the particular town where you live; even if the proximity to significant tornadoes is similar, particular places can take on risk prone or risk avoidant status. Since many devastatingly violent tornadoes (≥EF4) have tracked through the center of Moore and along Interstate Highway 35, but the intense tornadoes affecting Norman have largely been at their most intense along the outskirts of Norman's city limits, Moore's heightened perceptions of risk could be due in part to the more memorable tornadoes affecting areas people interact with more (Fig. 3h). However, many of the Norman respondents live within 5 mi of the intense tornadoes that have affected Moore. In some circumstances, being close to a tornado increases the perception of risk as noted previously, but in others (as in Norman) the effect might not be as straightforward.

4. Summary and conclusions

Previous research has revealed mixed effects of tornado climatology on tornado risk perception, and it is apparent that such perceptions differ substantially due to influences of tornado recency and distance. While there is some evidence that recent tornadoes increase one's perception of risk (Suls et al. 2013; Silver and Andrey 2014), this has shown to diminish as distance from the path increases (Suls et al. 2013). Research has also shown that it is possible for distant tornadoes, or

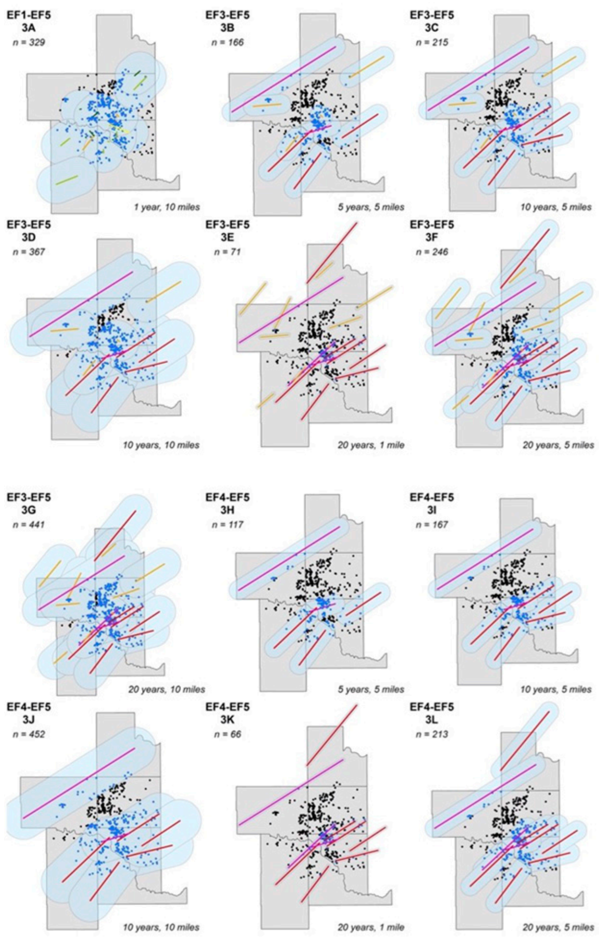

FIG. 3. Buffer analysis of tornado tracks (1996–2016) to reflect statistically significant findings in *t*-test tables, in relation to time since, distance from, and intensity of tornadoes. The number of respondents *n* within specified mile radii is shaded in blue.

events not experienced directly, to continue having a positive effect over longer time frames (Demuth 2018). These inconsistencies make it difficult to generalize the impacts of the placement and timing of tornadoes on perceptions of risk, especially since overall recollections of tornado climatology can be flawed (Ellis et al. 2018). In addition to relying on whether or not someone has had either direct or indirect experience, people may also rely on culturally constructed ideas of local tornado climatology to assess their danger (Klockow et al. 2014). Prior research revealed that some places take on risk-prone or risk-avoidant status for reasons that appear to be tied to local geographic imaginaries (Klockow et al. 2014; Peppler et al. 2018); however, the relationship between those imaginaries and climatology remains unclear.

Our research aimed to help fill a gap in understanding by examining the effect of many tornadoes of *all* intensities on individual risk perceptions, including particularly the effect of weaker tornadoes, whereas previous studies largely have been case studies analyzing the impacts of violent tornado events (≥EF4). Our research found that it is not necessarily about the number of tornadoes that have occurred, but how many intense (≥EF4) and recent (≤10 yr) tornadoes have occurred nearby (≤10 mi). Tornadoes have the most positive impact on risk perception when they are intense, close, and recent, but when tornadoes are relatively weak (≤EF3) and recent, they have a negative effect on risk perception that is maximized when they are nearby (e.g., within 10 mi).

Because of limitations in sample size and distribution, too few respondents were recorded as having experience with tornadoes within 1 year and 1 mi to analyze this group directly. No statistical analyses were computed to compare this with respondents who had not experienced this situation. For this reason, our study also differs from previous research studies that focused on very small spatiotemporal scales.

After spatial analysis (see Fig. 3), we noted some regional trends, and some places where our general findings did not apply well to specific communities. Respondents living northeast of downtown OKC have not experienced a violent tornado in some time, and their average perceptions of risk were lower generally than elsewhere in the metropolitan area. In the Moore–Norman example, densely populated portions of Norman have been affected by nonviolent tornadoes, potentially invoking the inoculation effect. However, violent (≥EF4) tornadoes have affected the city in recent years, as well as other intense tornadoes coming very close to the city, without the apparent positive effect on risk perception that accumulated elsewhere.

In the end, based on our work and past work, tornado experience is multifaceted, and the ways people interpret and apply those experiences to contextualize their risk from future events is nuanced, leading to mixed perceptions of risk proneness that are not necessarily obvious or expected from our distance from, time since, and intensity analyses. Individual experiences may lead to widely different interpretations or opinions of such feelings that require a deeper look than our data can provide. To this end, future research could assess the possibility of a "cancellation" effect on risk perceptions when there are both violent and nonviolent tornadoes nearby. However, it may be that culturally constructed tornado climatologies in their place of residence motivate people to amplify or reduce their feelings of risk. More studies are needed to understand the cognitive biases in people who encounter evidence that challenges their conceptions of local tornado climatology.

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TABLE A1. Kruskal–Wallis H tests for distance, time, and intensity. The distance Kruskal–Wallis H tests for differences between groups that have experienced any tornado (EF0–EF5) within the past 20 years at distances of 1, 5, 10, 15, and 20 mi. The time Kruskal–Wallis H tests for differences between groups that have experienced any tornado (EF0–EF5) within 20 mi of their residence at times of 1, 5, 10, or 20 years. The intensity Kruskal–Wallis H tests for differences between groups that have experienced tornadoes of intensity EF0–EF1, EF2–EF3, and EF4–EF5 within the past 20 years and 20 mi. One, two, or three asterisks indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Here, df indicates degrees of freedom.

				Test statistics		
	Ranks	N	Mean risk	χ^2	df	P value
Distance rating	1 mi	210	6.43	0.012	4	1
	5 mi	463	6.41			
	10 mi	463	6.41			
	15 mi	463	6.41			
	20 mi	463	6.41			
	Total	2062				
Time rating	1 yr	433	6.41	7.86×10^{-5}	3	1
	5 yr	463	6.41			
	10 yr	463	6.41			
	20 yr	463	6.41			
	Total	1822				
Intensity (EF scale) rating	EF0–EF5	9	7	0.052	2	0.97
	EF3–EF5	80	7.51			
	EF4–EF5	73	7.48			
	Total	162				

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APPENDIX

Results of the Kruskal–Wallis *H* Tests

Table A1 shows Kruskal–Wallis H tests for distance, time, and intensity.

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